MOFFAT
COLLECTION SYSTEM PROJECT

FINAL ENVIRONMENTAL IMPACT STATEMENT

Appendix E: Surface Water Resources

Photo provided courtesy of Denver Water.

MOFFAT
COLLECTION SYSTEM PROJECT
FINAL ENVIRONMENTAL IMPACT STATEMENT

Appendix E:
Surface Water Resources

Photo provided courtesy of Denver Water.

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Appendix E-1
Historical Reservoir Contents and Elevations

Note: All figures are for water years 1975-2004 to reflect existing conditions based on 30 years of data. Elevation and volume data were obtained from Denver Water and are presented in units of feet above mean sea level.

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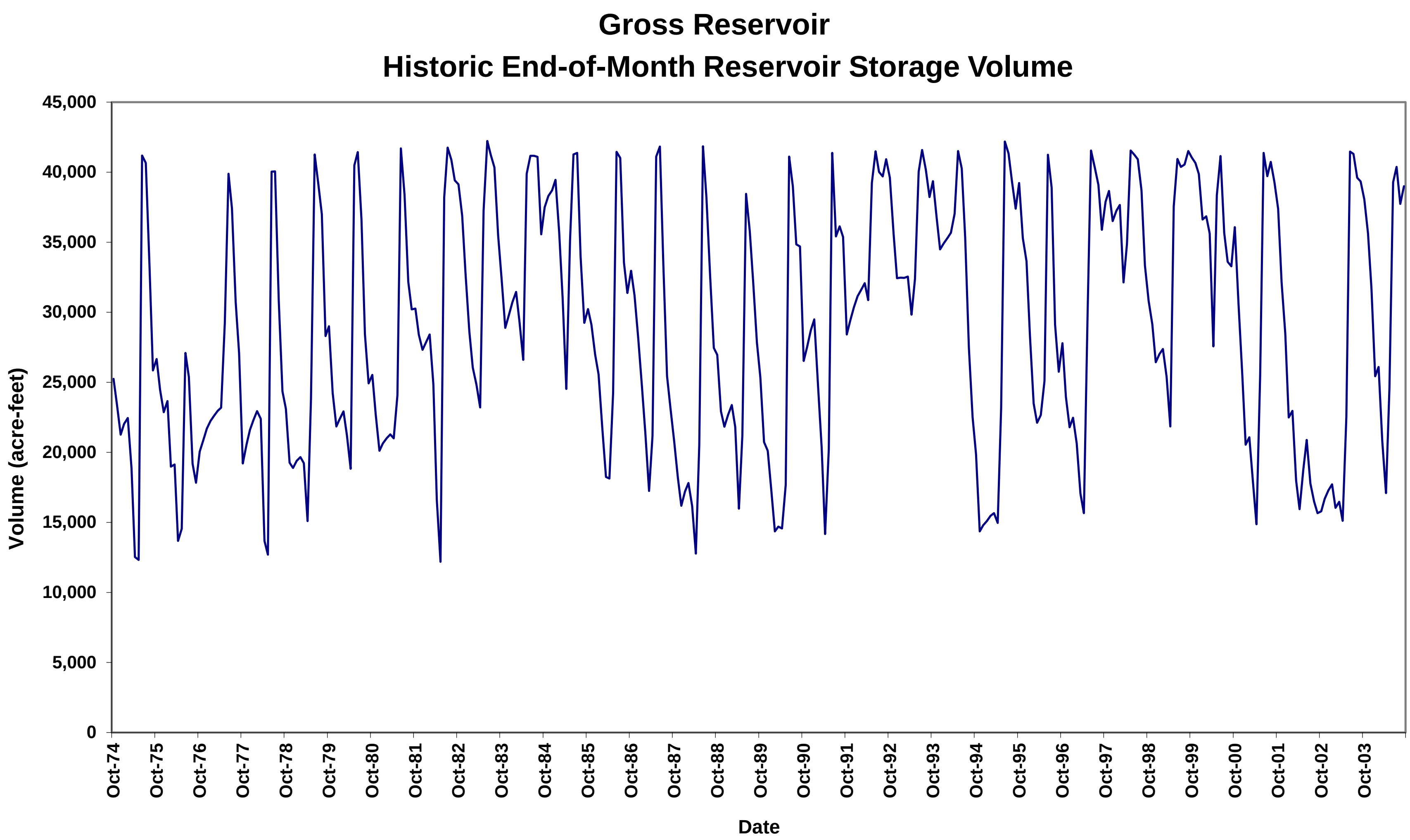
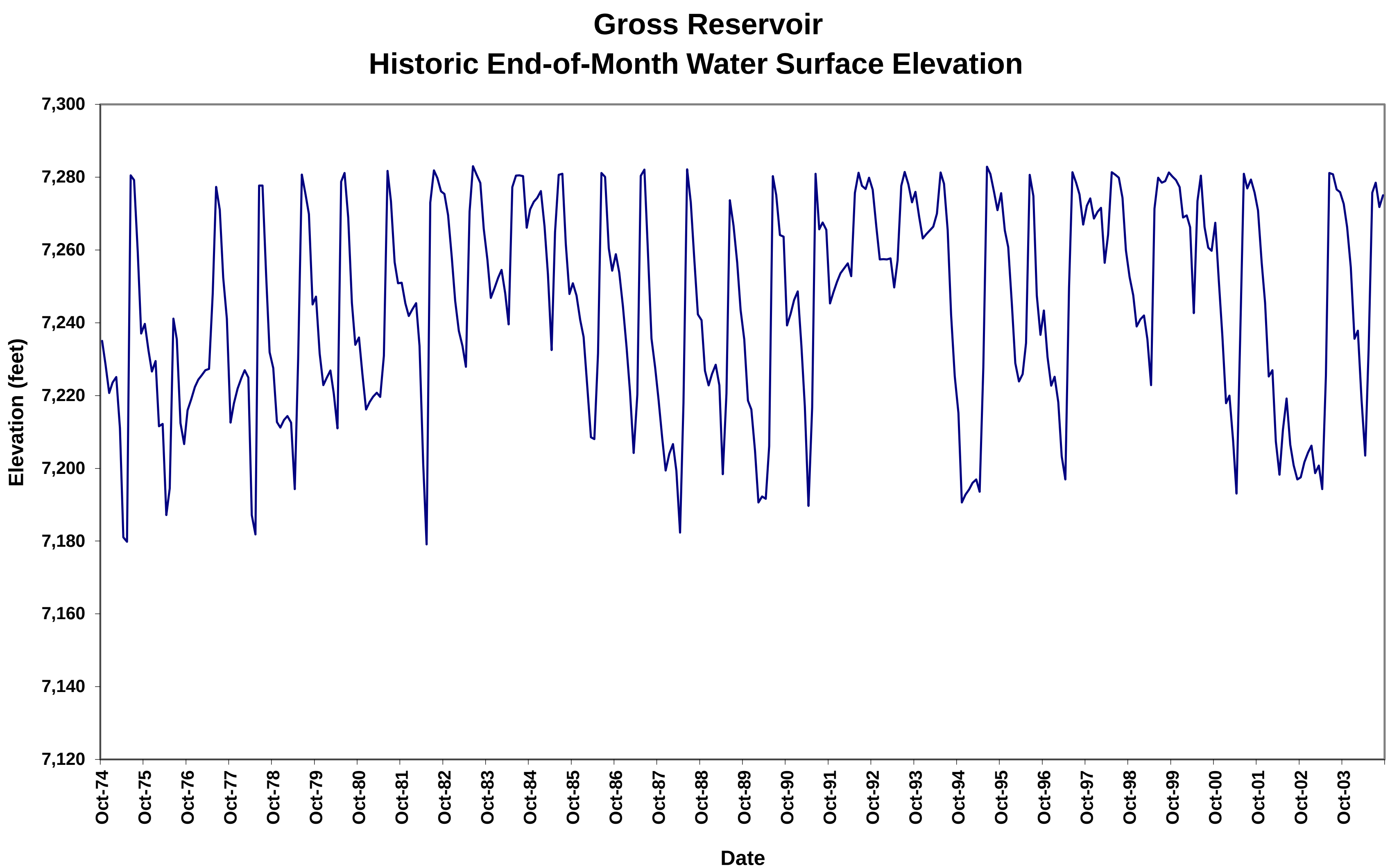
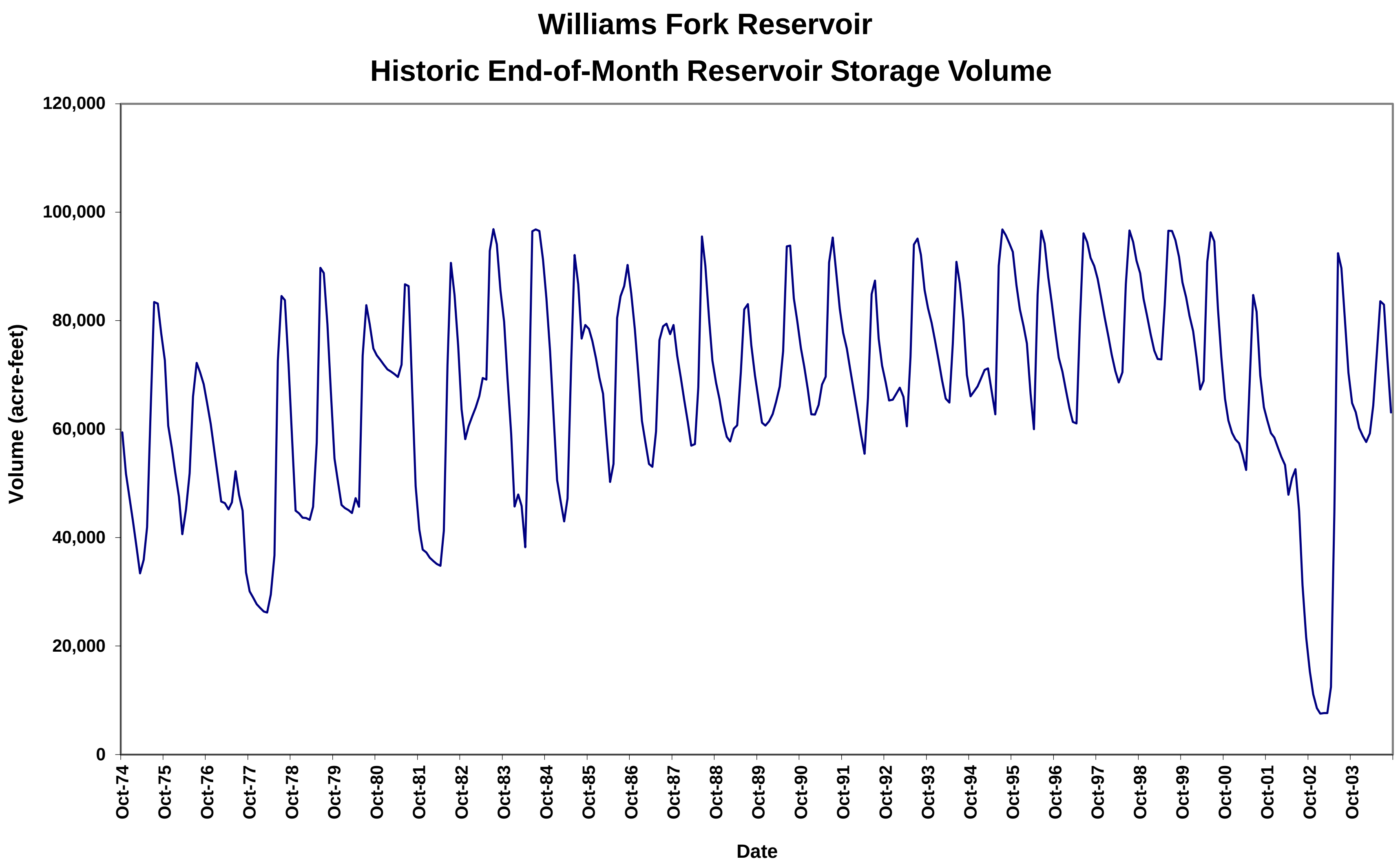
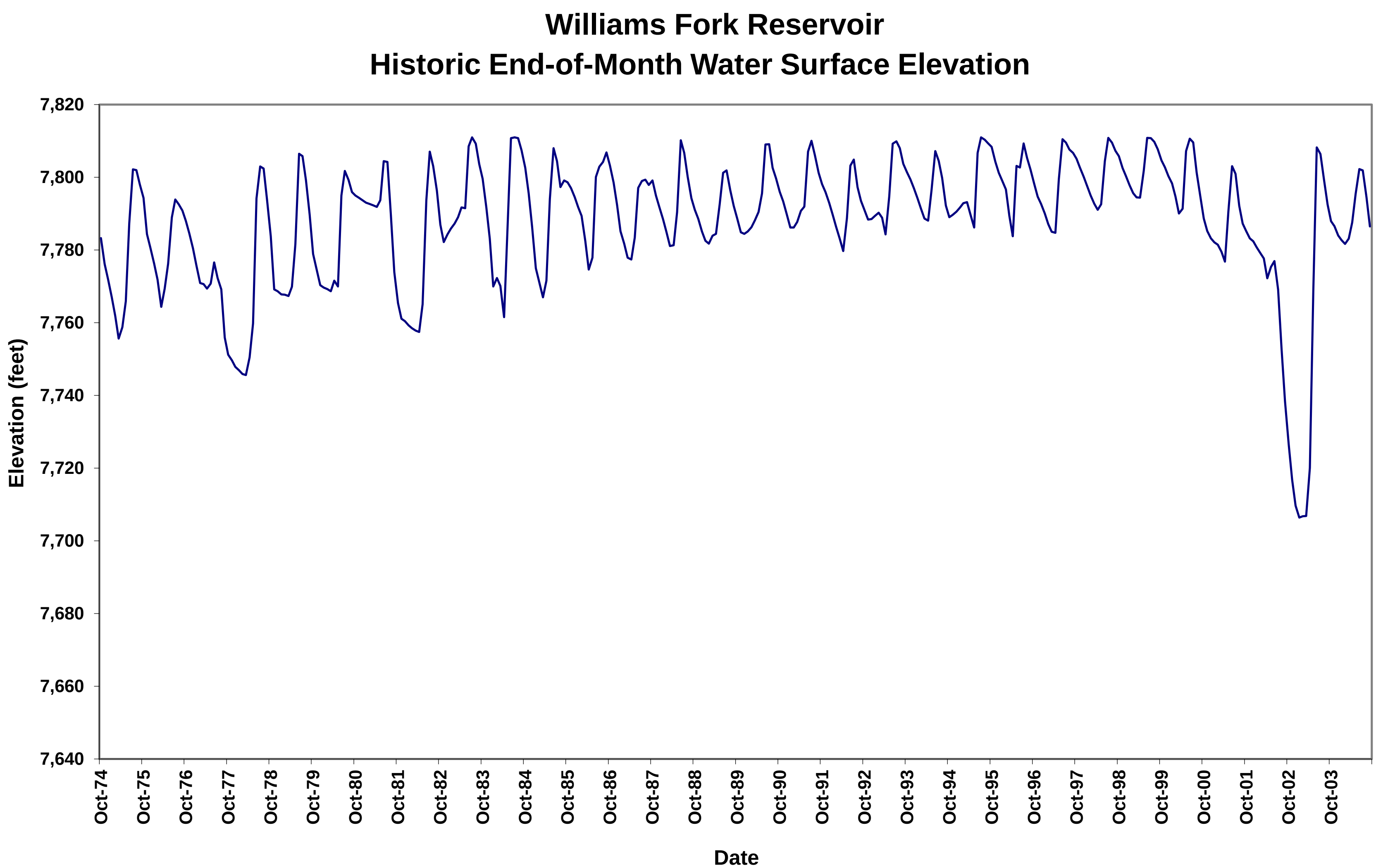
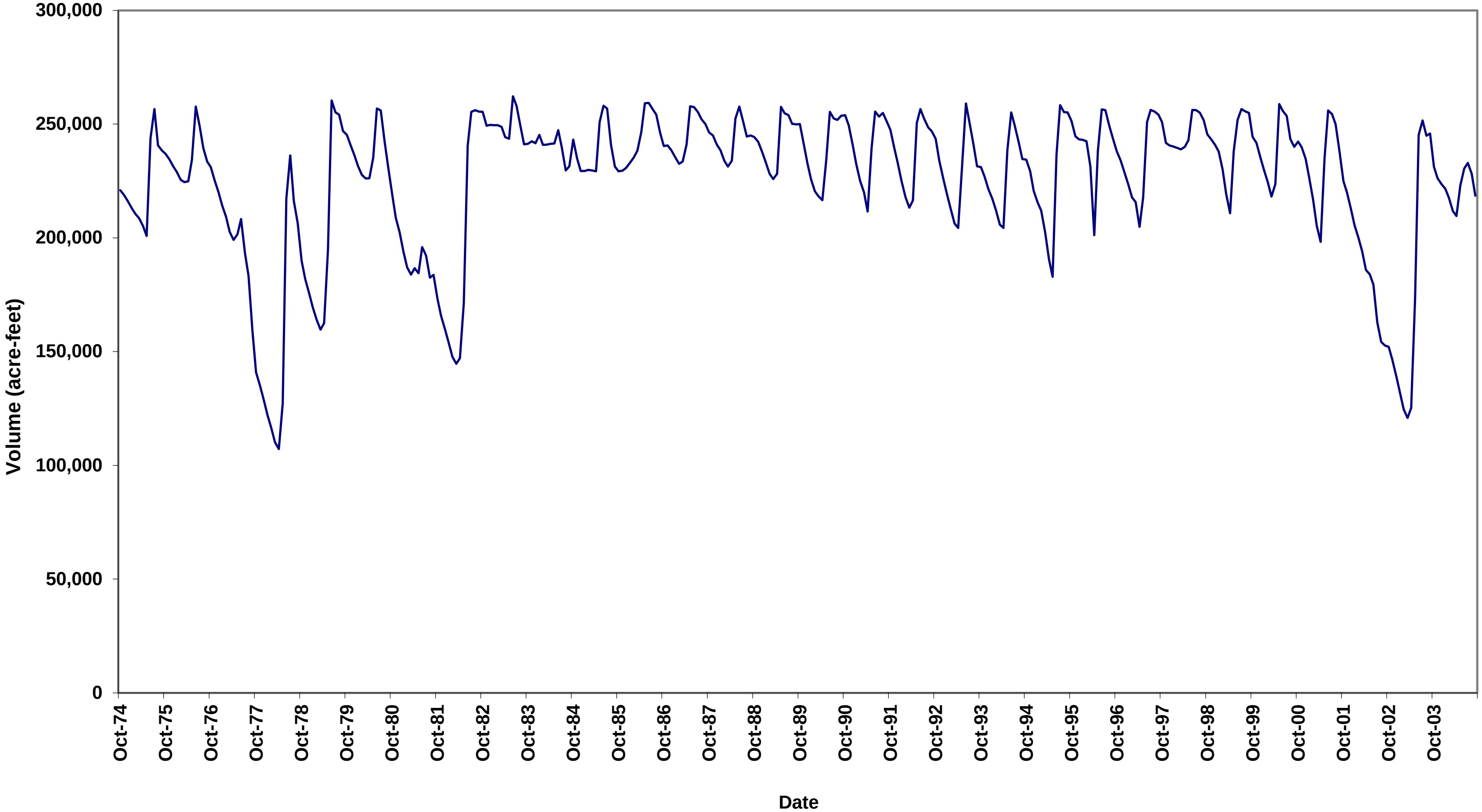

Gross Reservoir
Historic End-of-Month Reservoir Storage Volume
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Volume (acre-feet)
Oct-74
Oct-75
Oct-76
Oct-77
Oct-78
Oct-79
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00
Oct-01
Oct-02
Oct-03
Date

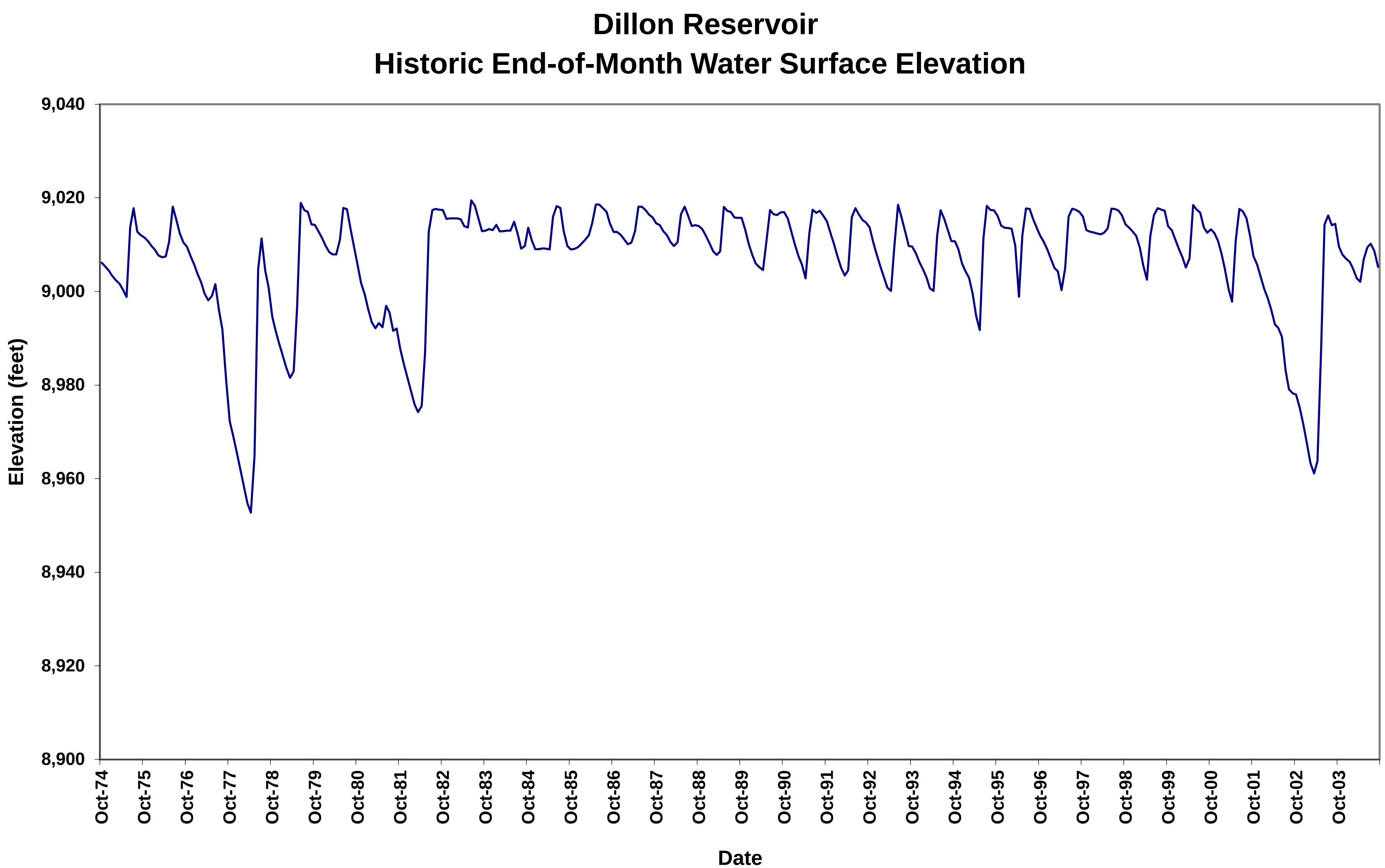

Gross Reservoir
Historic End-of-Month Water Surface Elevation
Elevation (feet)
7,300
7,280
7,260
7,240
7,220
7,200
7,180
7,160
7,140
7,120
Oct-74
Oct-75
Oct-76
Oct-77
Oct-78
Oct-79
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00
Oct-01
Oct-02
Oct-03
Date

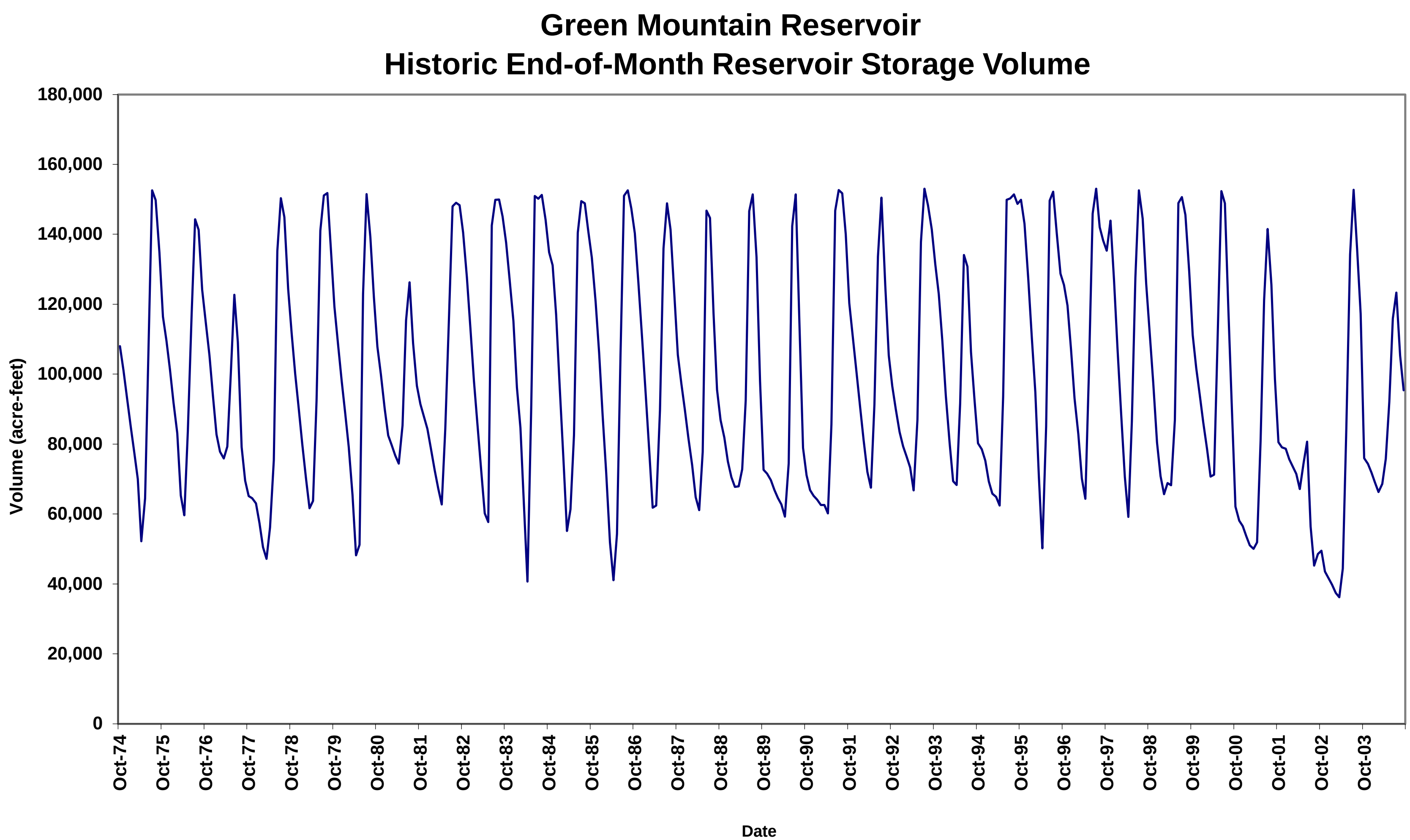

Williams Fork Reservoir
Historic End-of-Month Reservoir Storage Volume
Volume (acre-feet)
120,000
100,000
80,000
60,000
40,000
20,000
0
Oct-74
Oct-75
Oct-76
Oct-77
Oct-78
Oct-79
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00
Oct-01
Oct-02
Oct-03
Date


Williams Fork Reservoir
Historic End-of-Month Water Surface Elevation
Elevation (feet)
7,820
7,800
7,780
7,760
7,740
7,720
7,700
7,680
7,660
7,640
Oct-74
Oct-75
Oct-76
Oct-77
Oct-78
Oct-79
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00
Oct-01
Oct-02
Oct-03
Date

Dillon Reservoir
Historic End-of-Month Reservoir Storage Volume

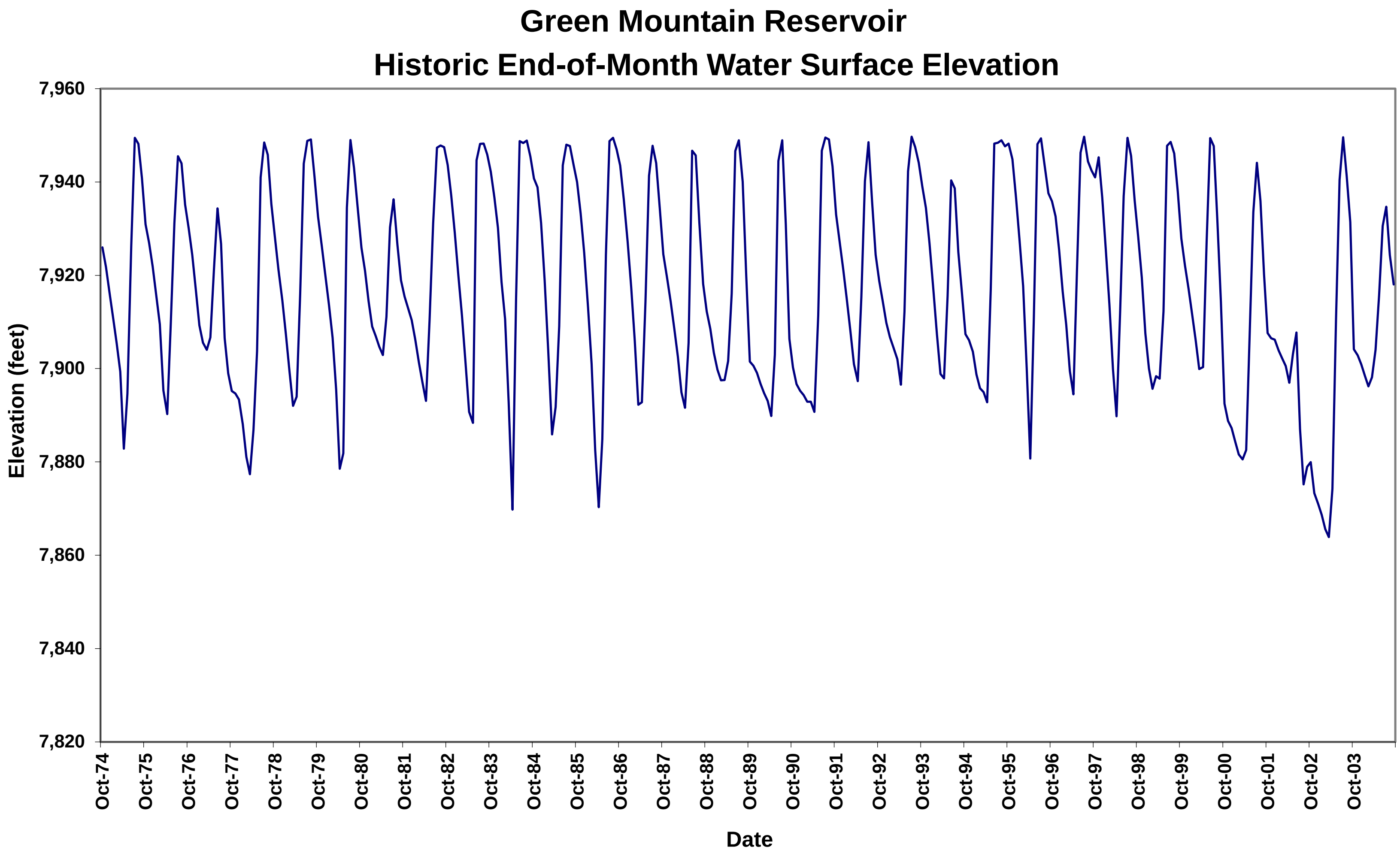



Dillon Reservoir
Historic End-of-Month Water Surface Elevation
Elevation (feet)
9,040
9,020
9,000
8,980
8,960
8,940
8,920
8,900
Oct-74
Oct-75
Oct-76
Oct-77
Oct-78
Oct-79
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00
Oct-01
Oct-02
Oct-03
Date

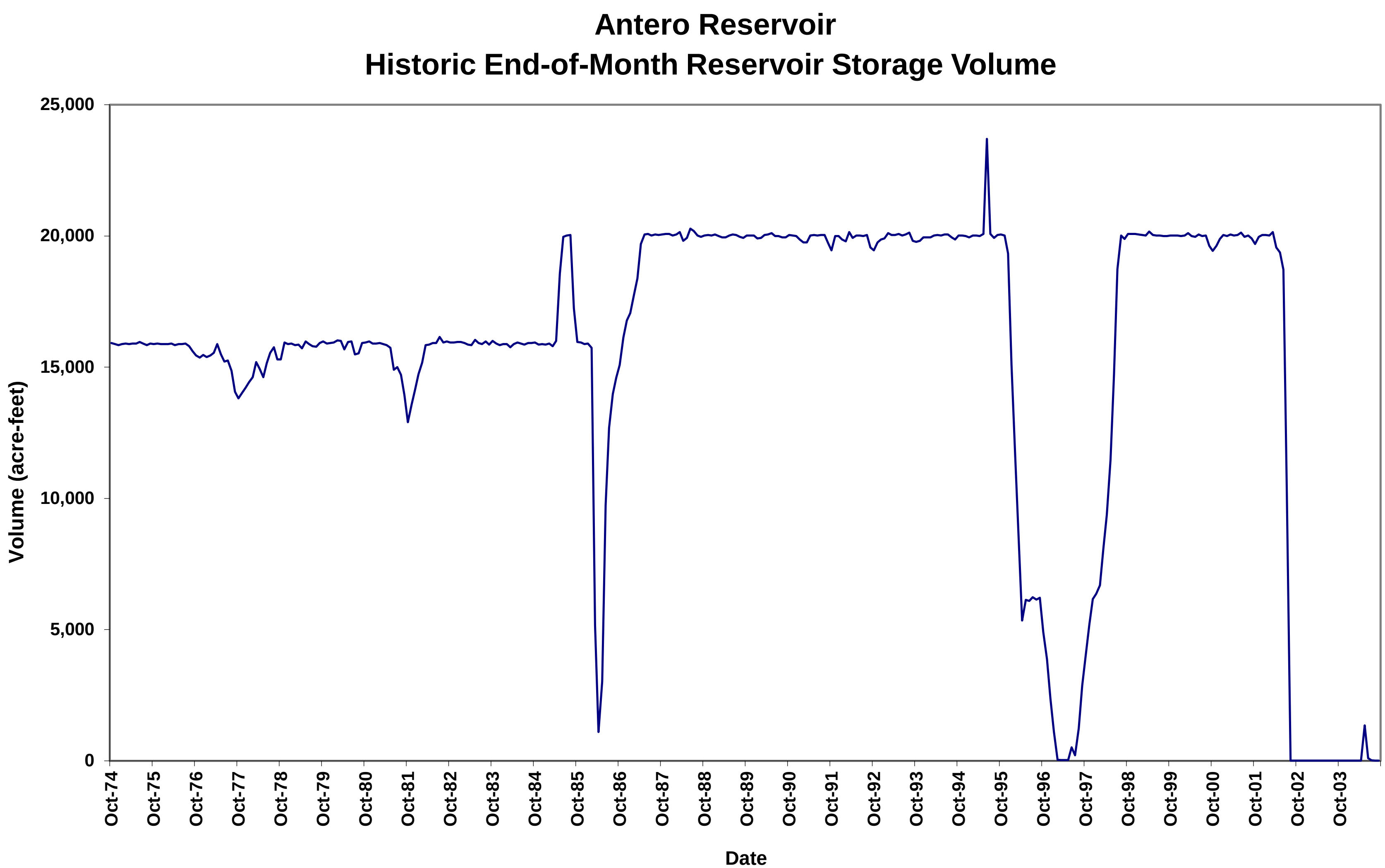


Note: See FEIS Section 5.1.1.2 under the Blue River Stream Flow subsection for a discussion of the differences between historical and modeled reservoir contents and water surface elevations.

Appendix E-1
Historical Reservoir Contents and Elevations



Note: See FEIS Section 5.1.1.2 under the Blue River Stream Flow subsection for a discussion of the differences between historical and modeled reservoir contents and water surface elevations.


Antero Reservoir
Historic End-of-Month Reservoir Storage Volume
Volume (acre-feet)
25,000
20,000
15,000
10,000
5,000
0
Oct-74
Oct-75
Oct-76
Oct-77
Oct-78
Oct-79
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
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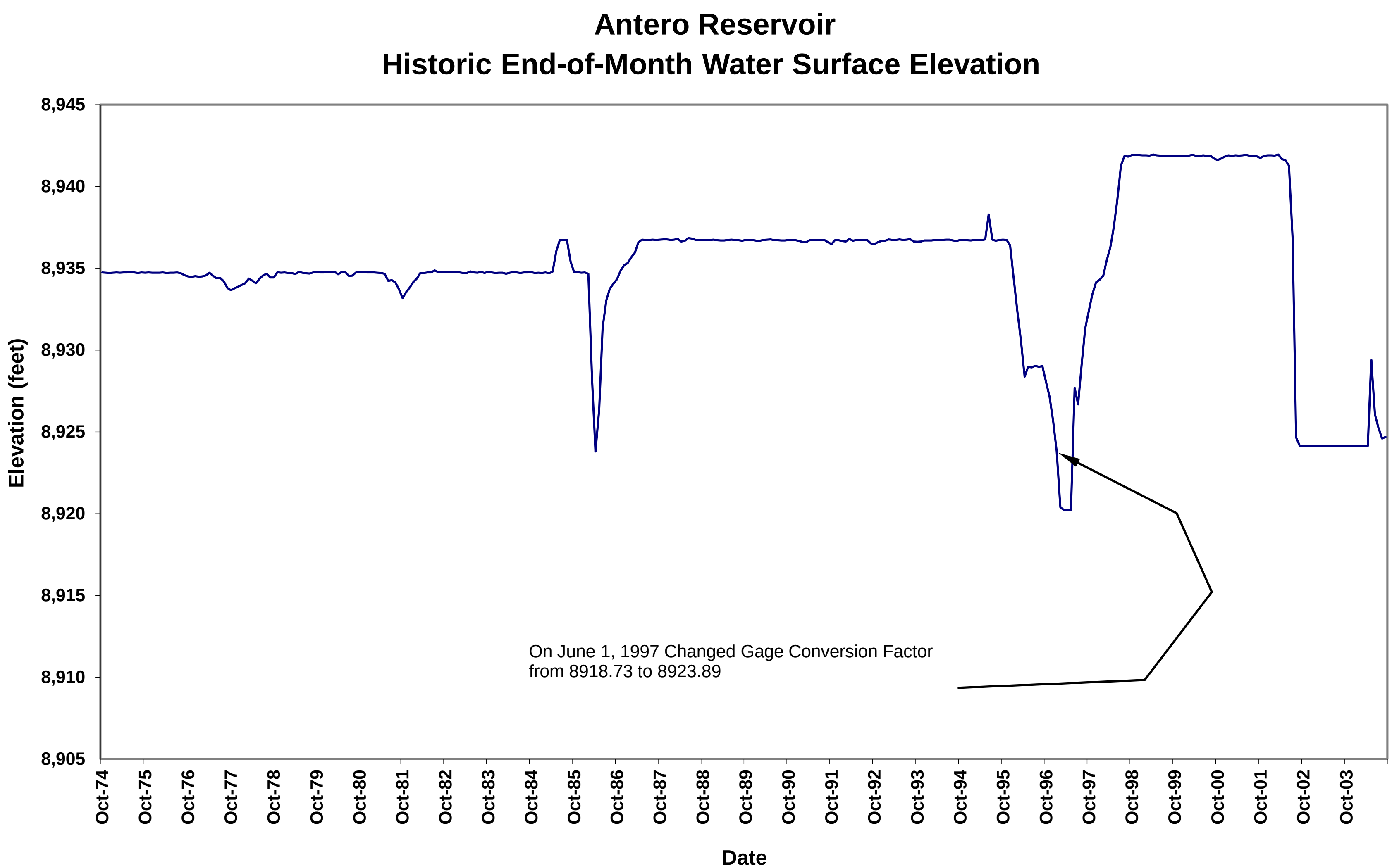
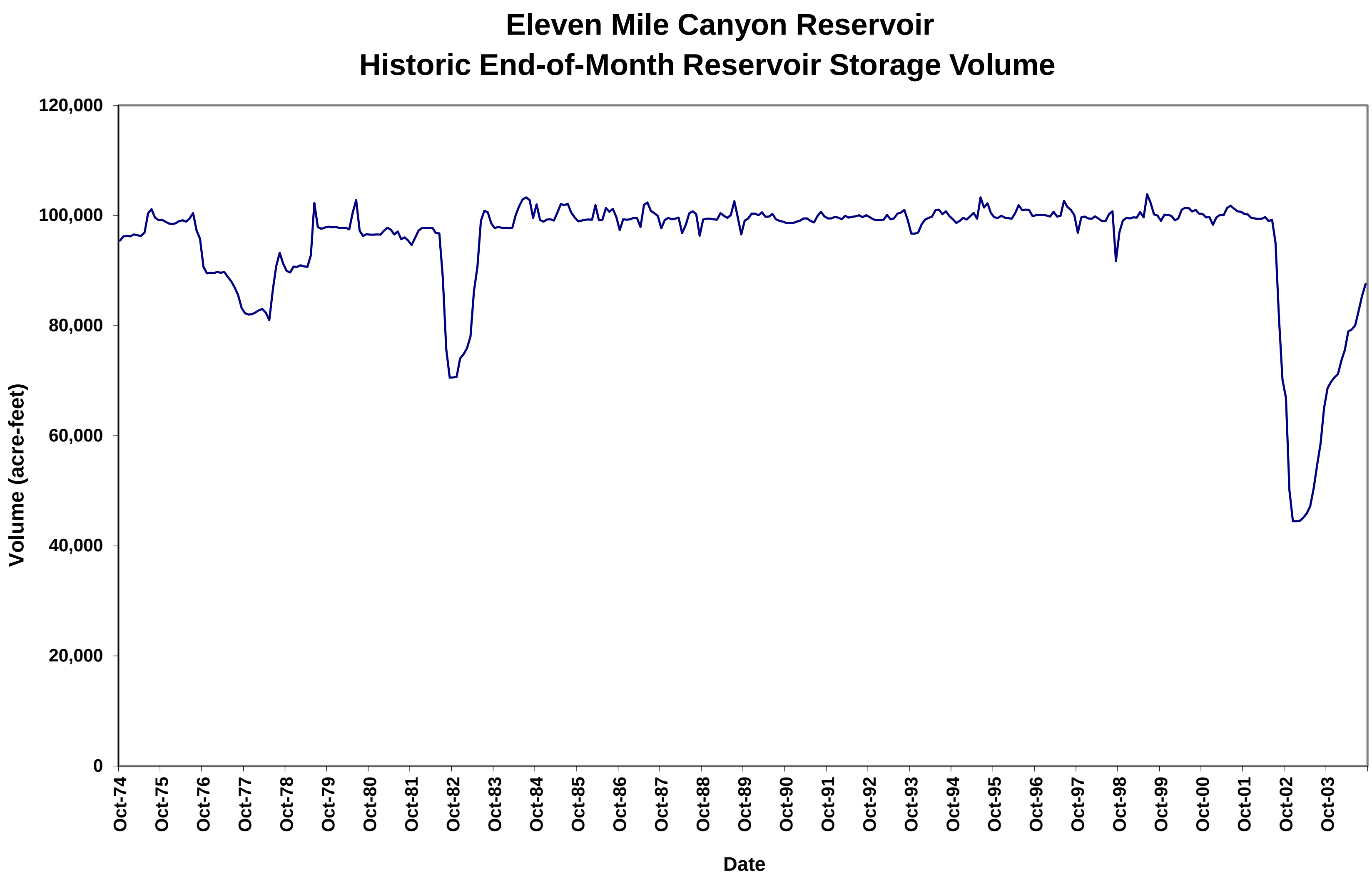
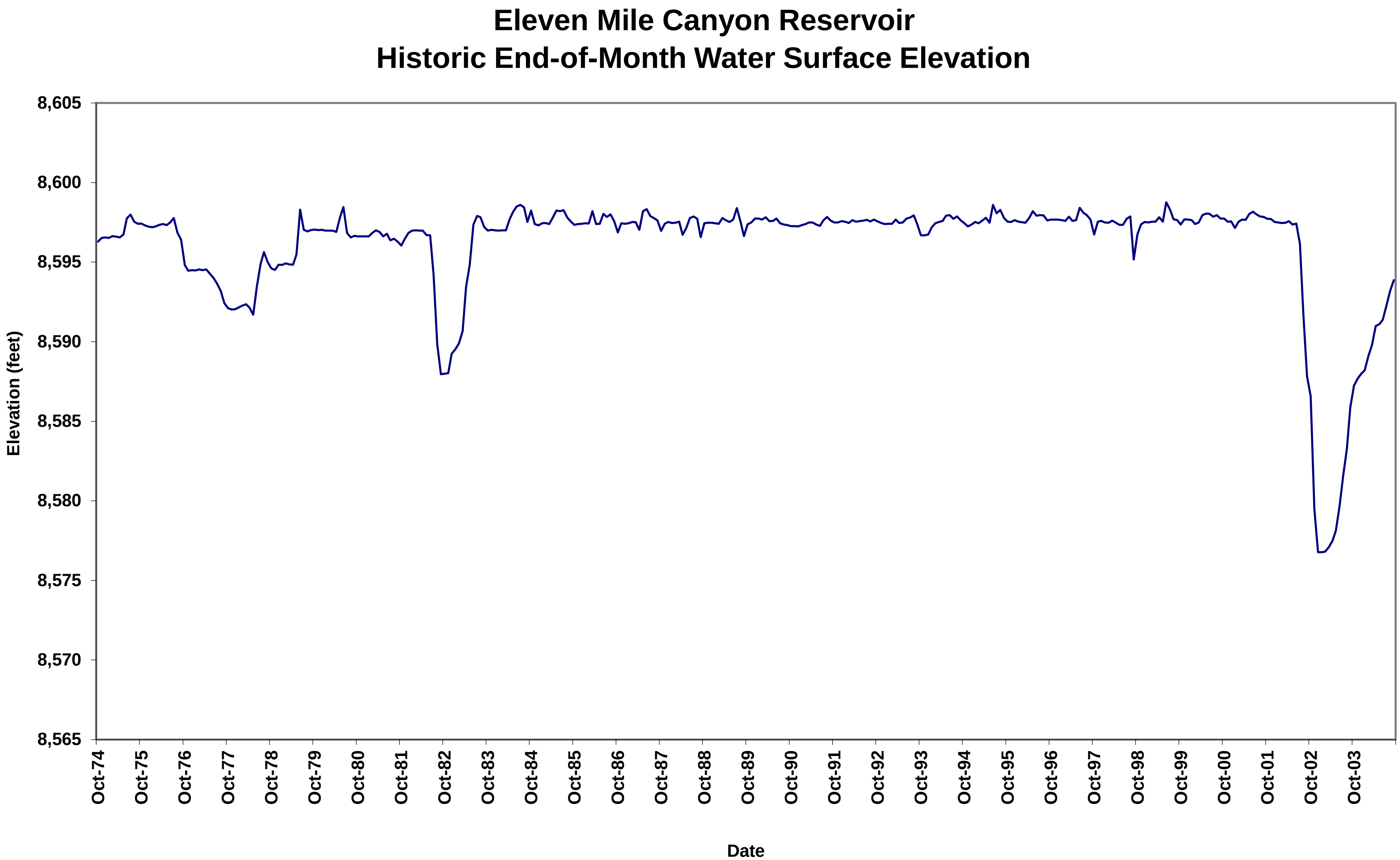
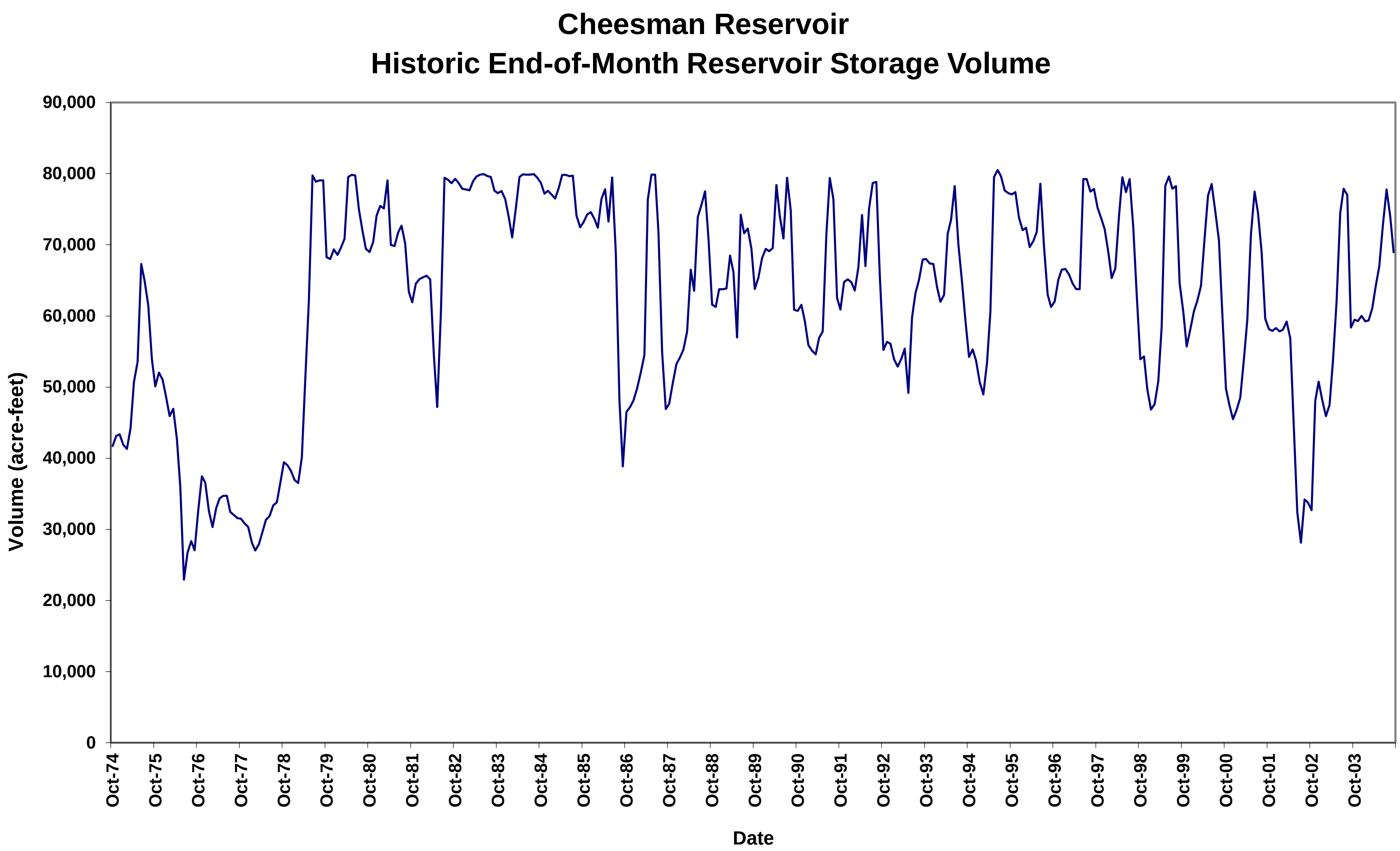
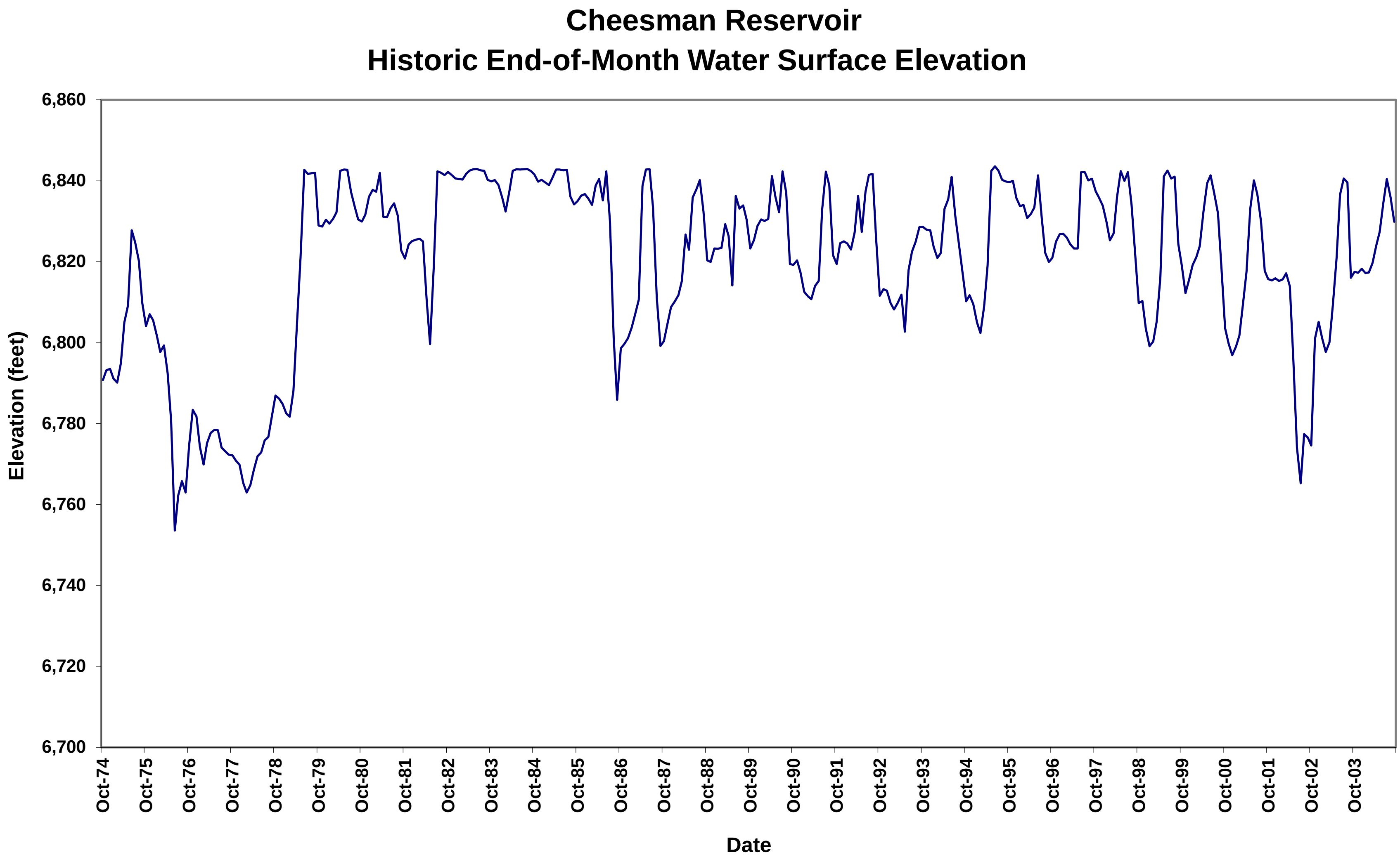
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00
Oct-01
Oct-02
Oct-03
Date


Antero Reservoir
Historic End-of-Month Water Surface Elevation
Elevation (feet)
8,945
8,940
8,935
8,930
8,925
8,920
8,915
8,910
8,905
Oct-74 Oct-75 Oct-76 Oct-77 Oct-78 Oct-79 Oct-80 Oct-81 Oct-82 Oct-83 Oct-84 Oct-85 Oct-86 Oct-87 Oct-88 Oct-89 Oct-90 Oct-91 Oct-92 Oct-93 Oct-94 Oct-95 Oct-96 Oct-97 Oct-98 Oct-99 Oct-00 Oct-01 Oct-02 Oct-03
Date
On June 1, 1997 Changed Gage Conversion Factor
from 8918.73 to 8923.89


Eleven Mile Canyon Reservoir
Historic End-of-Month Reservoir Storage Volume
Volume (acre-feet)
120,000
100,000
80,000
60,000
40,000
20,000
0
Oct-74
Oct-75
Oct-76
Oct-77
Oct-78
Oct-79
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00
Oct-01
Oct-02
Oct-03
Date

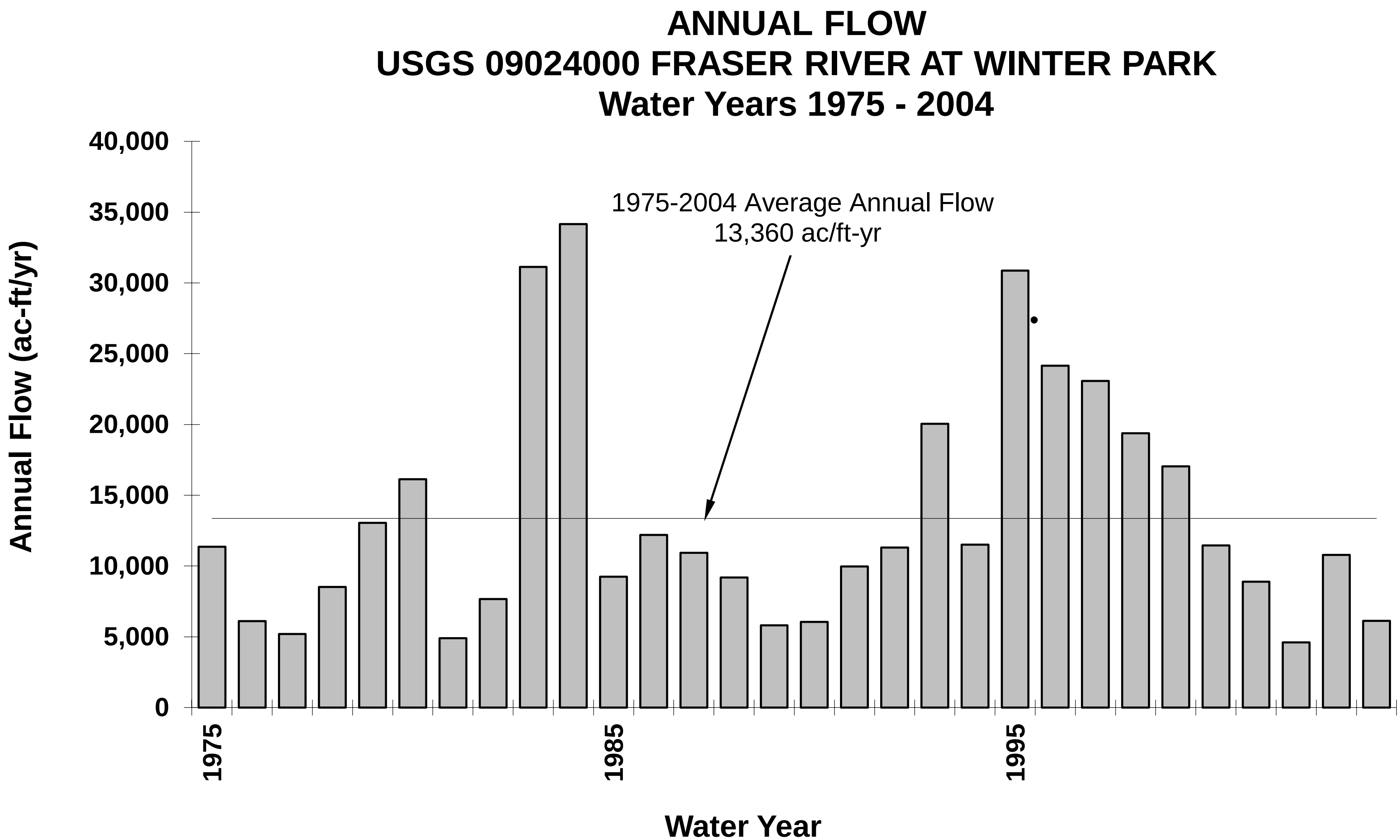

Eleven Mile Canyon Reservoir
Historic End-of-Month Water Surface Elevation
Elevation (feet)
8,605
8,600
8,595
8,590
8,585
8,580
8,575
8,570
8,565
Oct-74
Oct-75
Oct-76
Oct-77
Oct-78
Oct-79
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00
Oct-01
Oct-02
Oct-03
Date

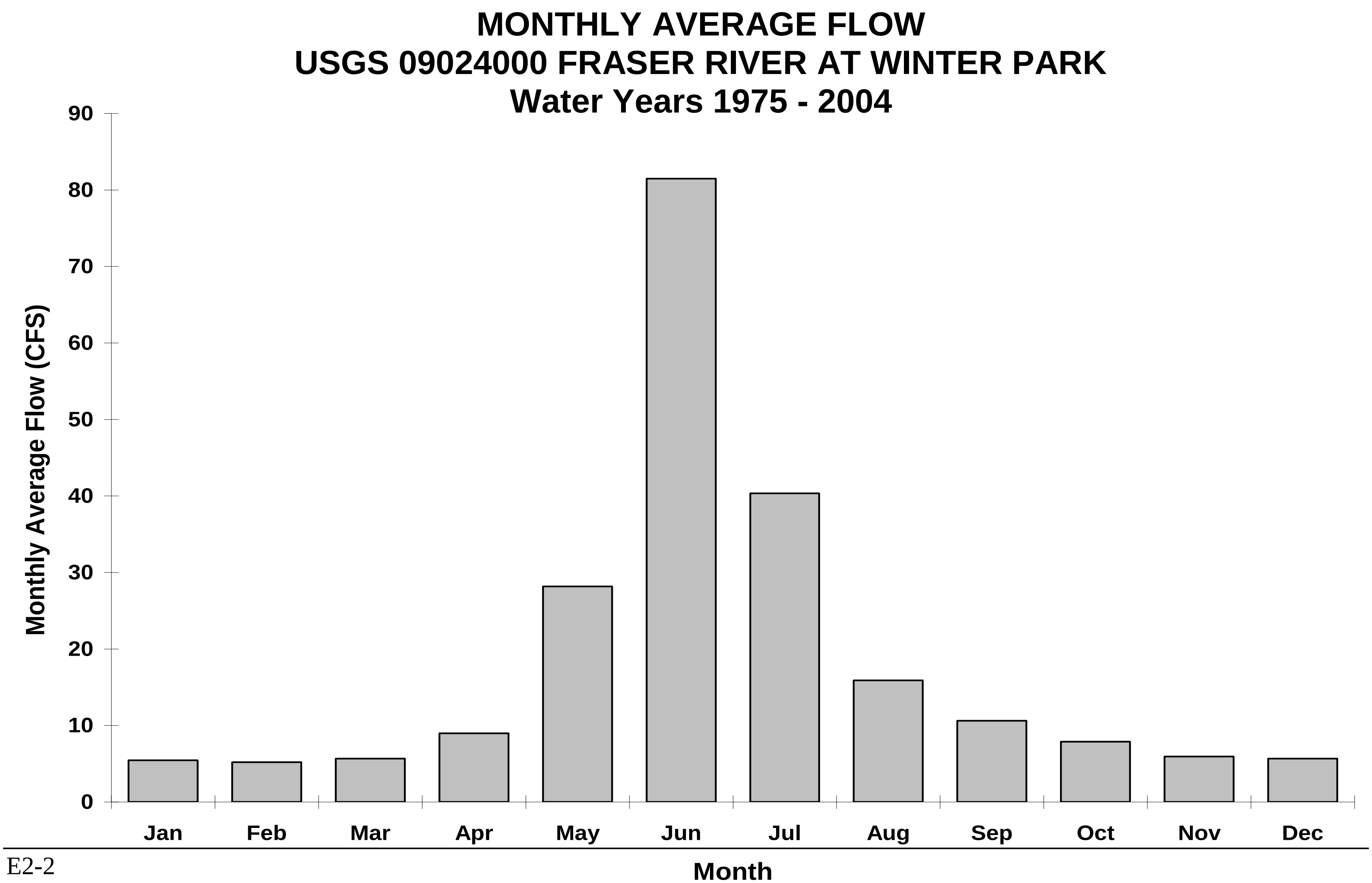

Cheesman Reservoir
Historic End-of-Month Reservoir Storage Volume
Volume (acre-feet)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Oct-74
Oct-75
Oct-76
Oct-77
Oct-78
Oct-79
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00
Oct-01
Oct-02
Oct-03
Date

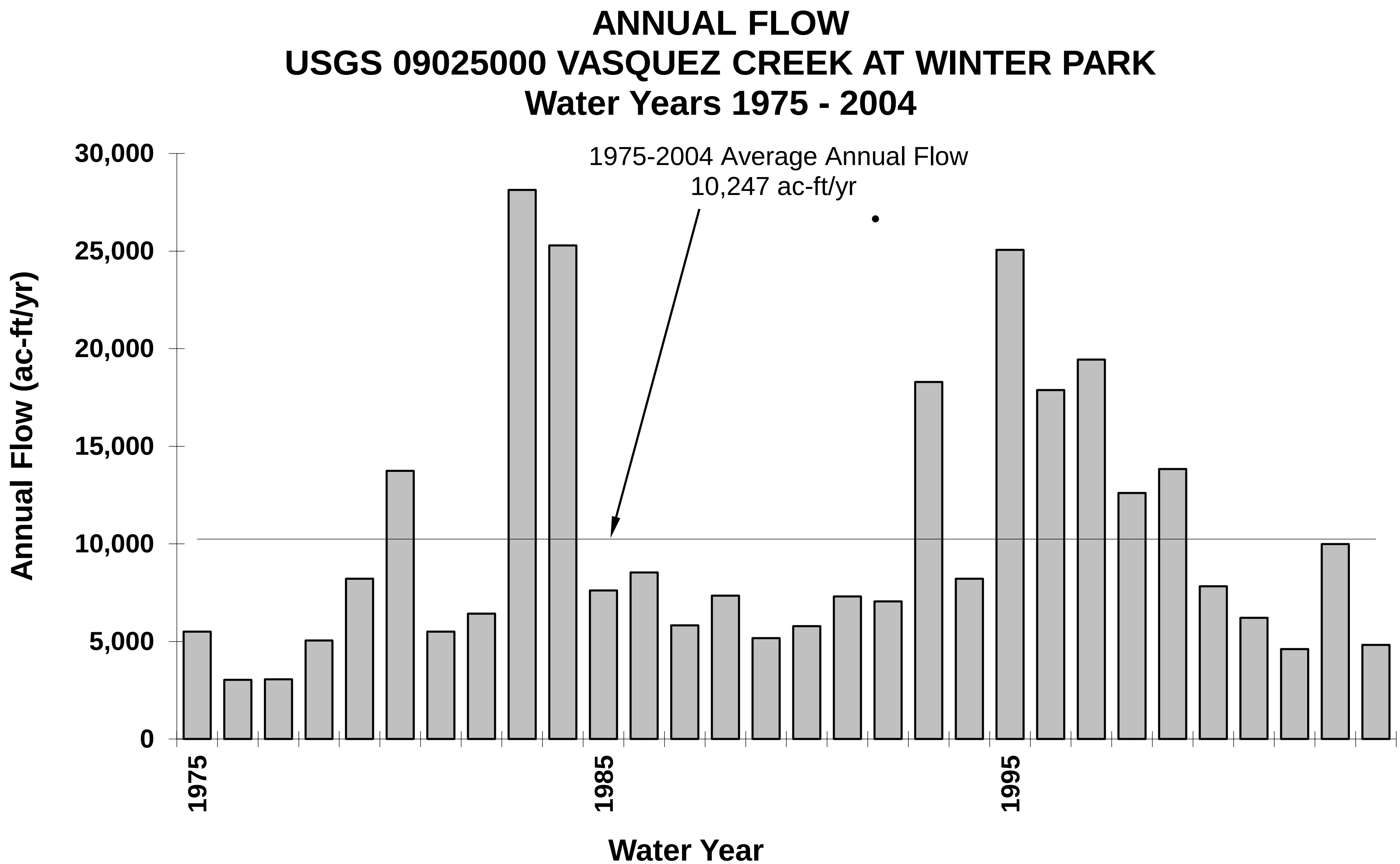

Cheesman Reservoir
Historic End-of-Month Water Surface Elevation
Elevation (feet)
6,860
6,840
6,820
6,800
6,780
6,760
6,740
6,720
6,700
Oct-74
Oct-75
Oct-76
Oct-77
Oct-78
Oct-79
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00
Oct-01
Oct-02
Oct-03
Date

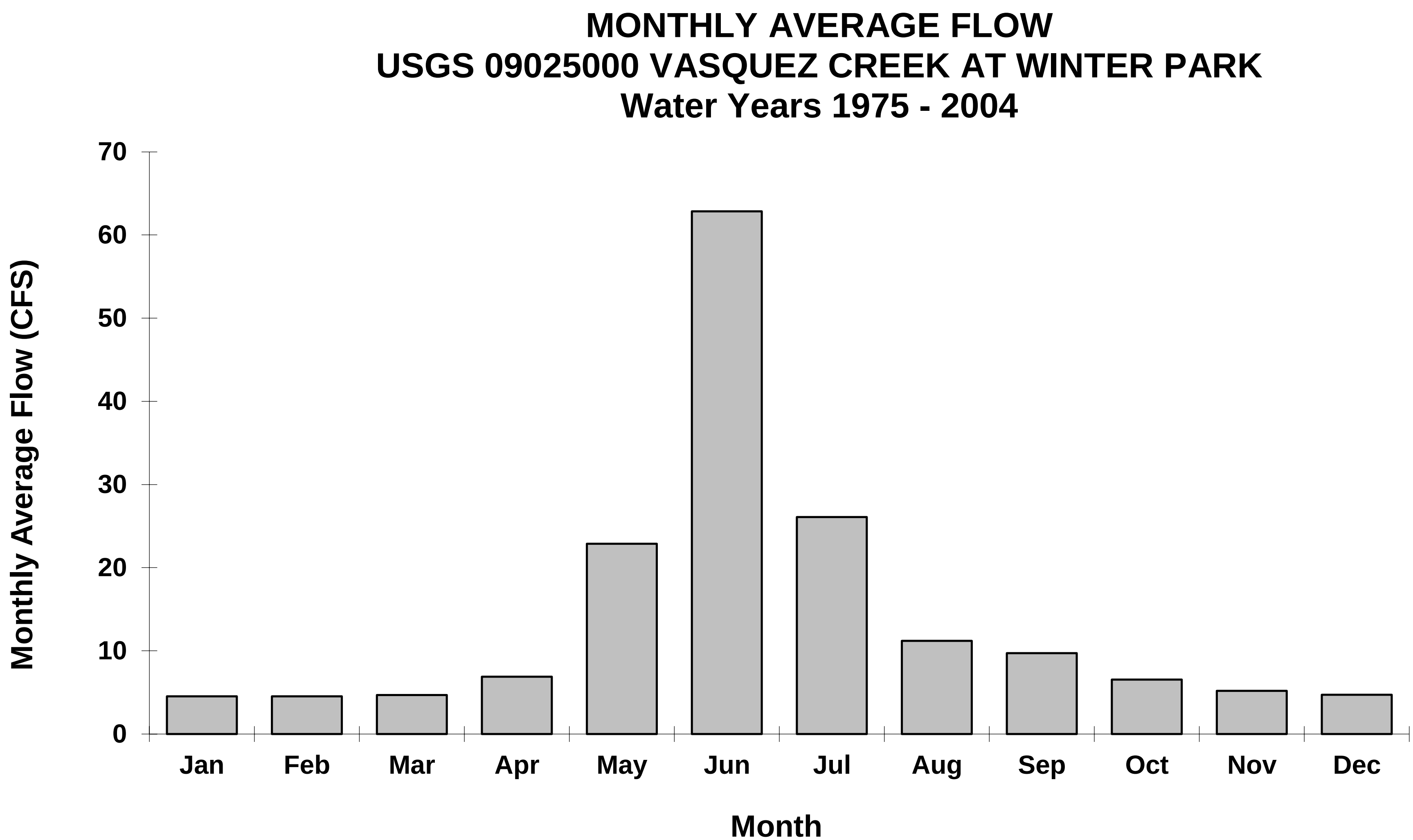
Appendix E-2
Historical Annual and Monthly Flow in Affected River Segments

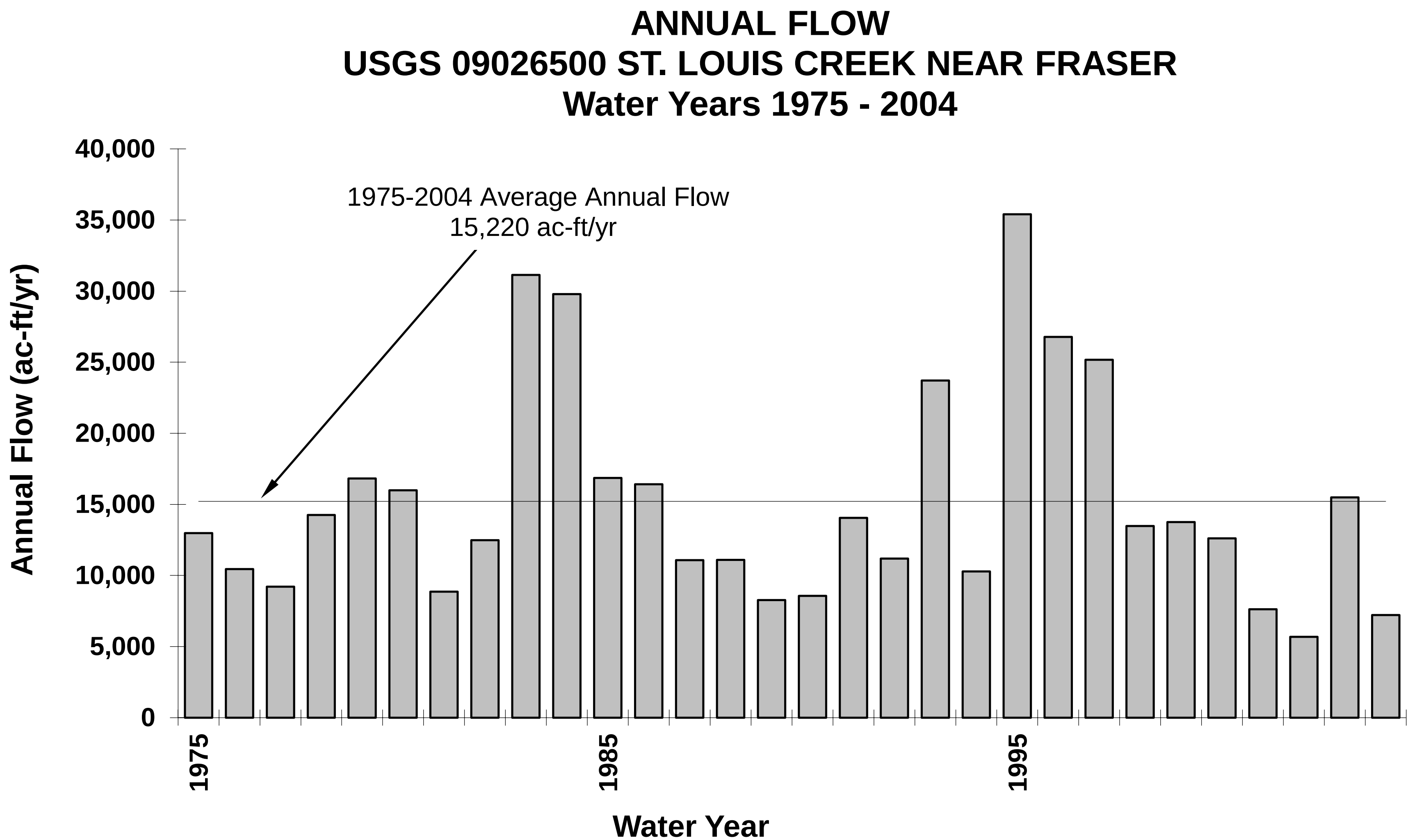
Appendix E-2
Historical Annual and Monthly Flow in Affected River Segments

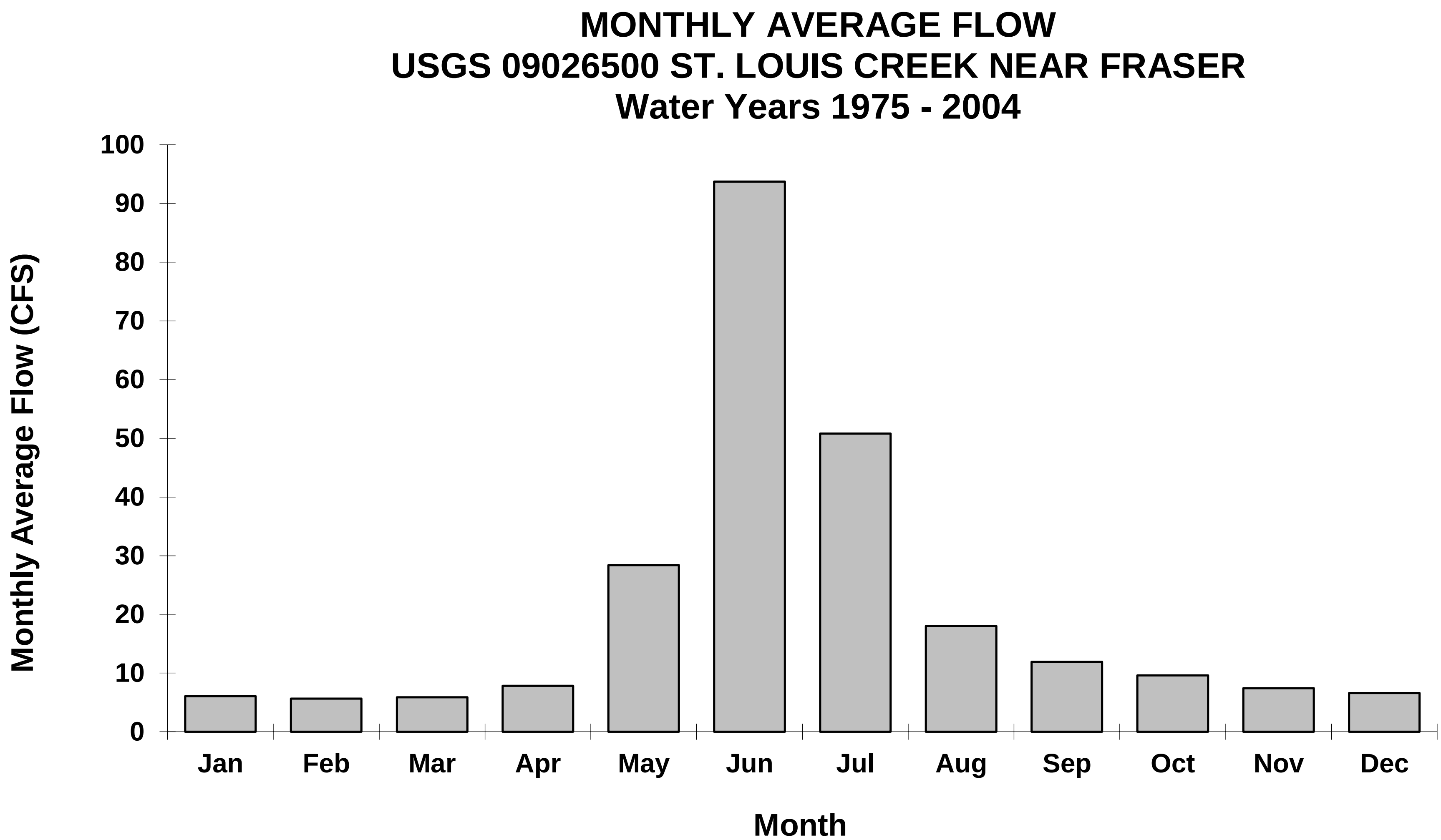

ANNUAL FLOW
USGS 09024000 FRASER RIVER AT WINTER PARK
Water Years 1975 - 2004
1975-2004 Average Annual Flow
13,360 ac/ft-yr
Annual Flow (ac-ft/yr)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1975
1985
1995
Water Year

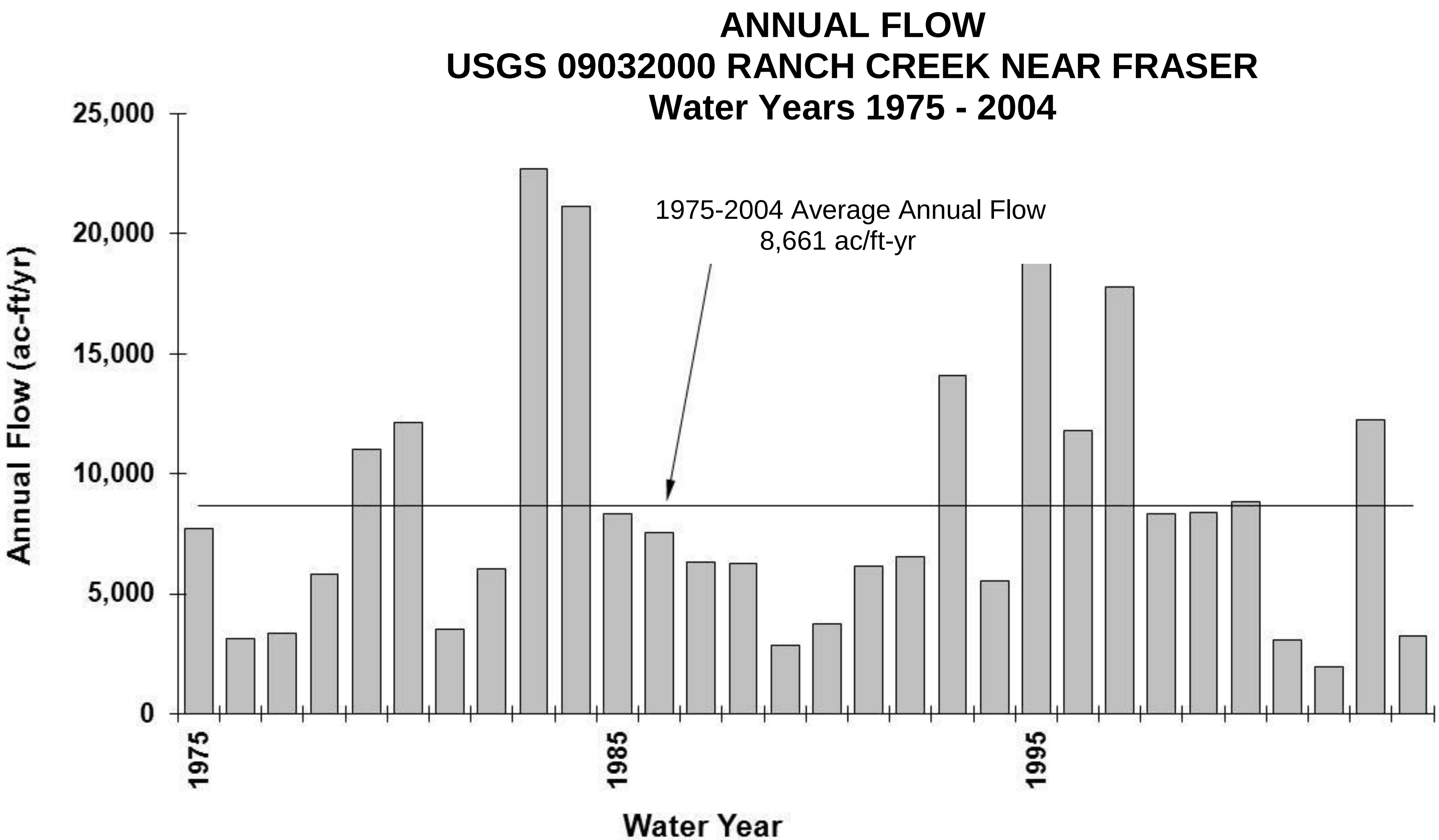

MONTHLY AVERAGE FLOW
USGS 09024000 FRASER RIVER AT WINTER PARK
Water Years 1975 - 2004
Monthly Average Flow (CFS)
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

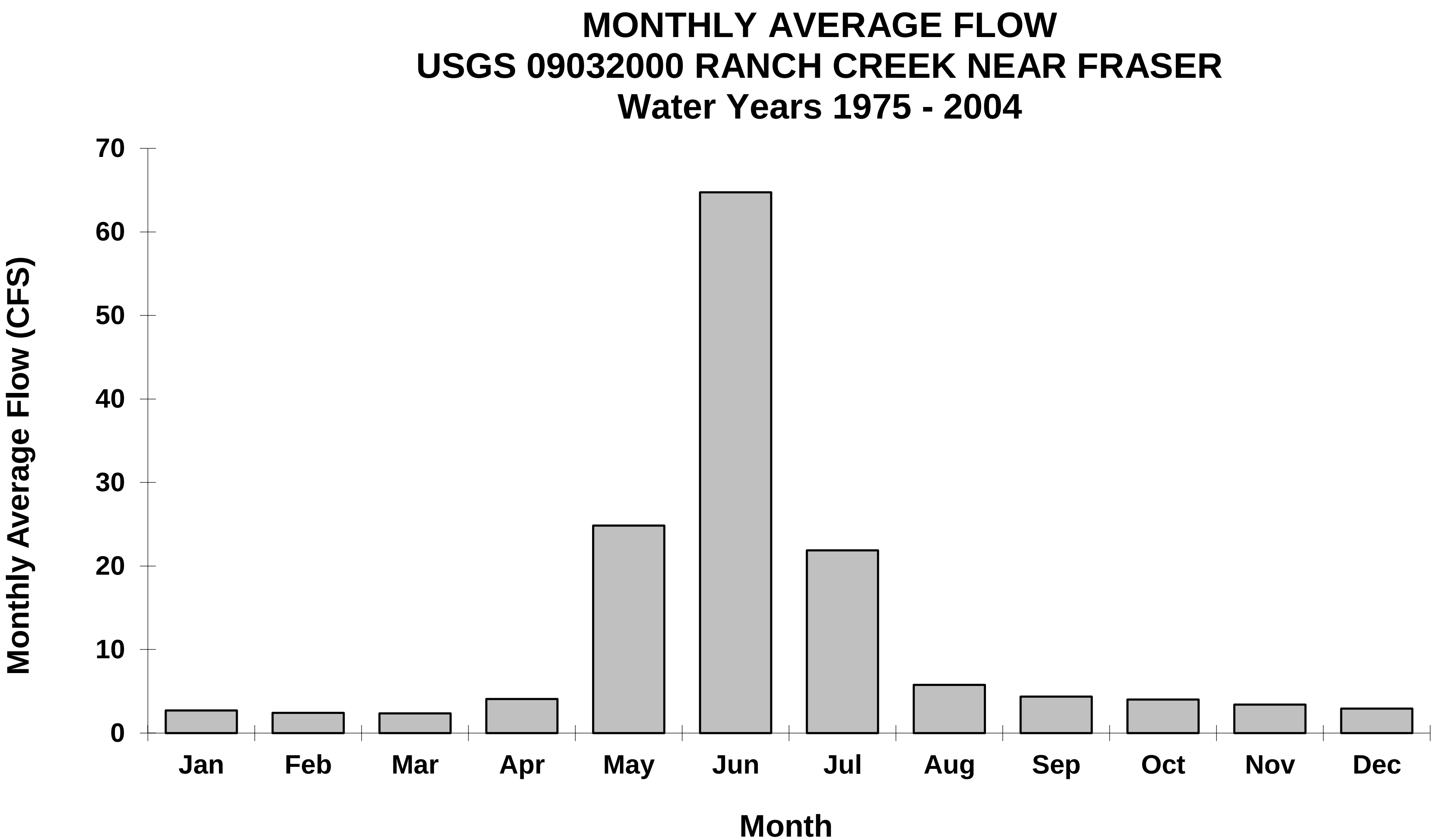

ANNUAL FLOW
USGS 09025000 VASQUEZ CREEK AT WINTER PARK
Water Years 1975 - 2004
1975-2004 Average Annual Flow
10,247 ac-ft/yr
Annual Flow (ac-ft/yr)
30,000
25,000
20,000
15,000
10,000
5,000
0
1975
1985
1995
Water Year

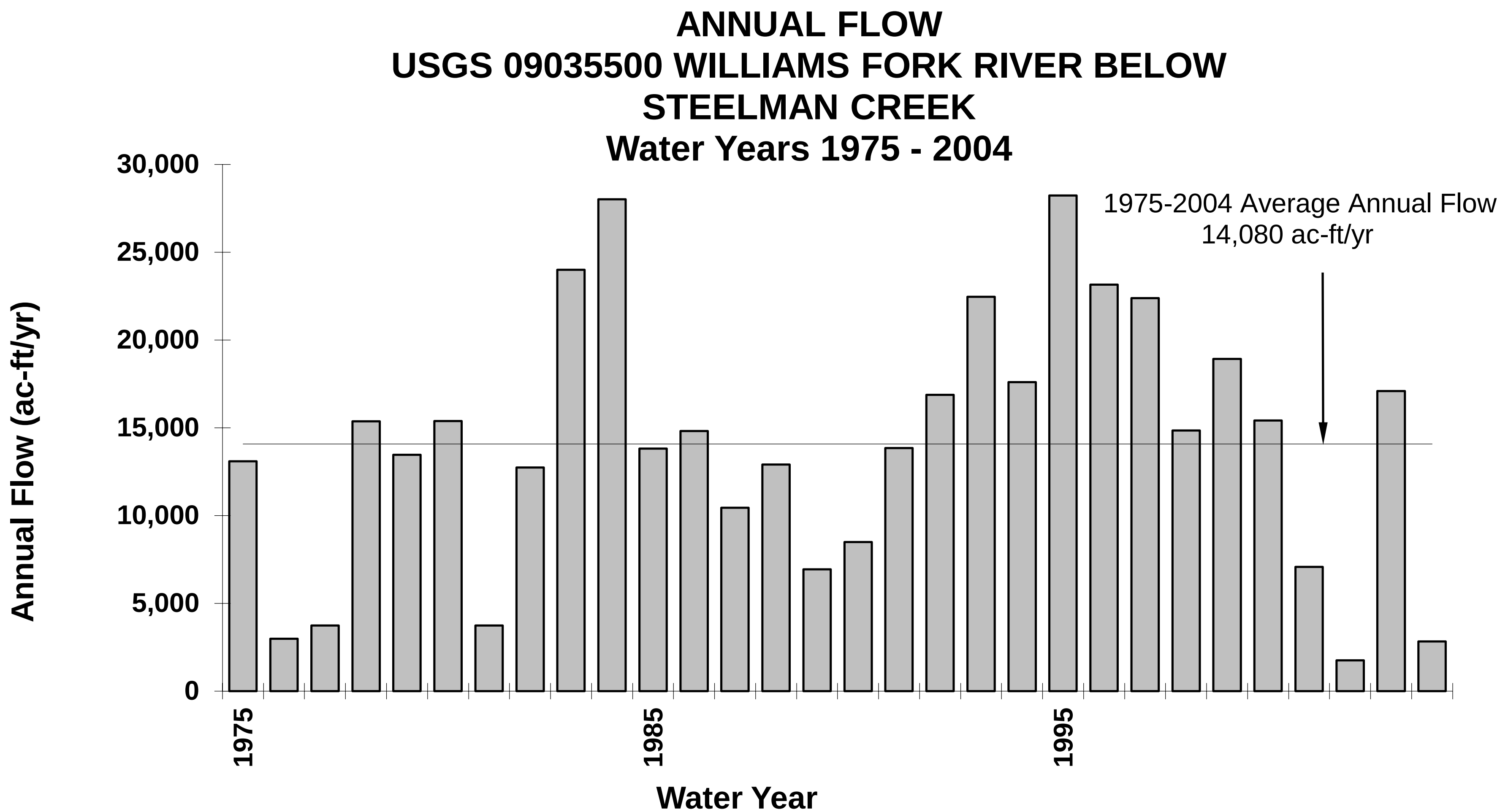

MONTHLY AVERAGE FLOW
USGS 09025000 VASQUEZ CREEK AT WINTER PARK
Water Years 1975 - 2004
Monthly Average Flow (CFS)
0
10
20
30
40
50
60
70
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

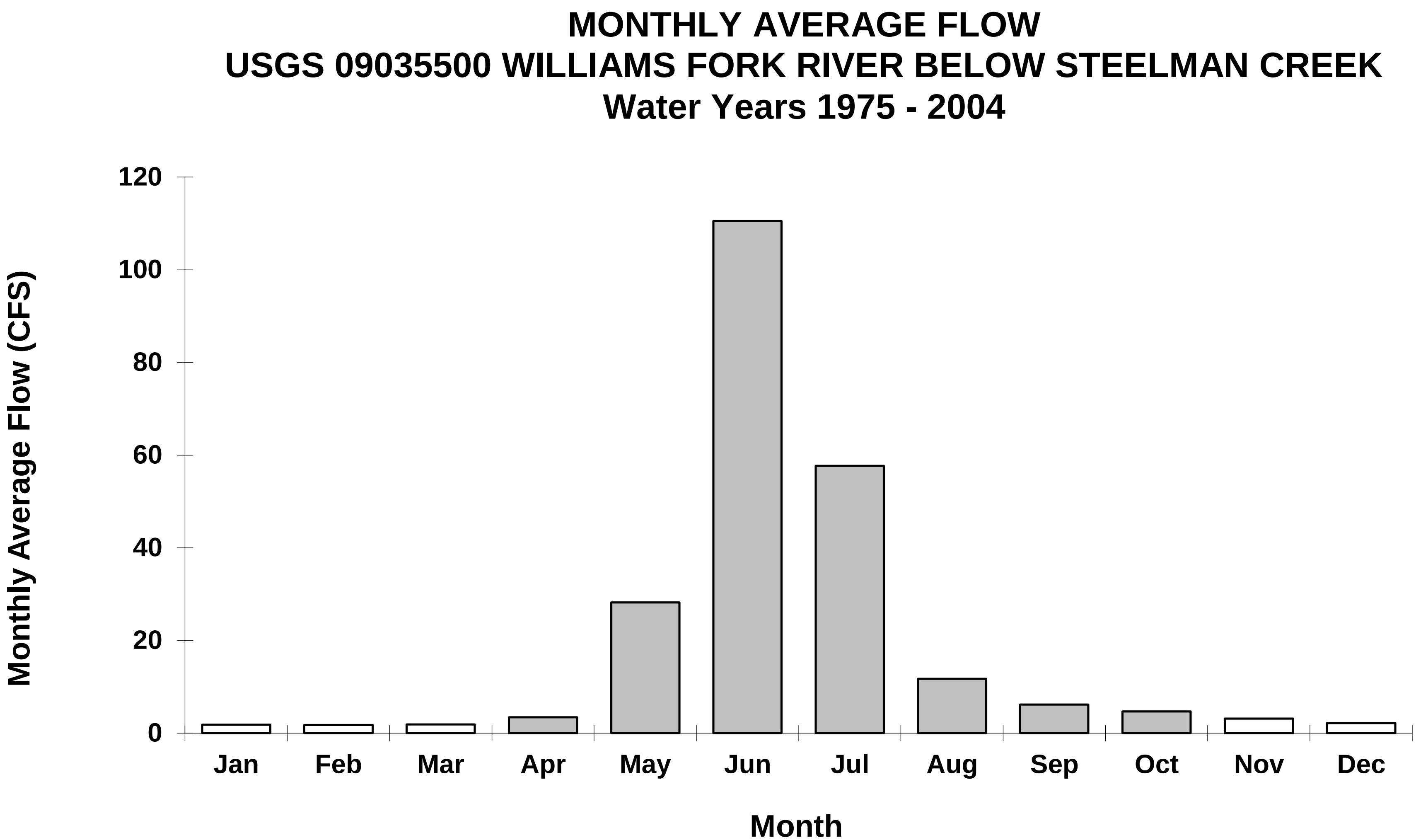

ANNUAL FLOW
USGS 09026500 ST. LOUIS CREEK NEAR FRASER
Water Years 1975 - 2004
1975-2004 Average Annual Flow
15,220 ac-ft/yr
Annual Flow (ac-ft/yr)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1975
1985
1995
Water Year

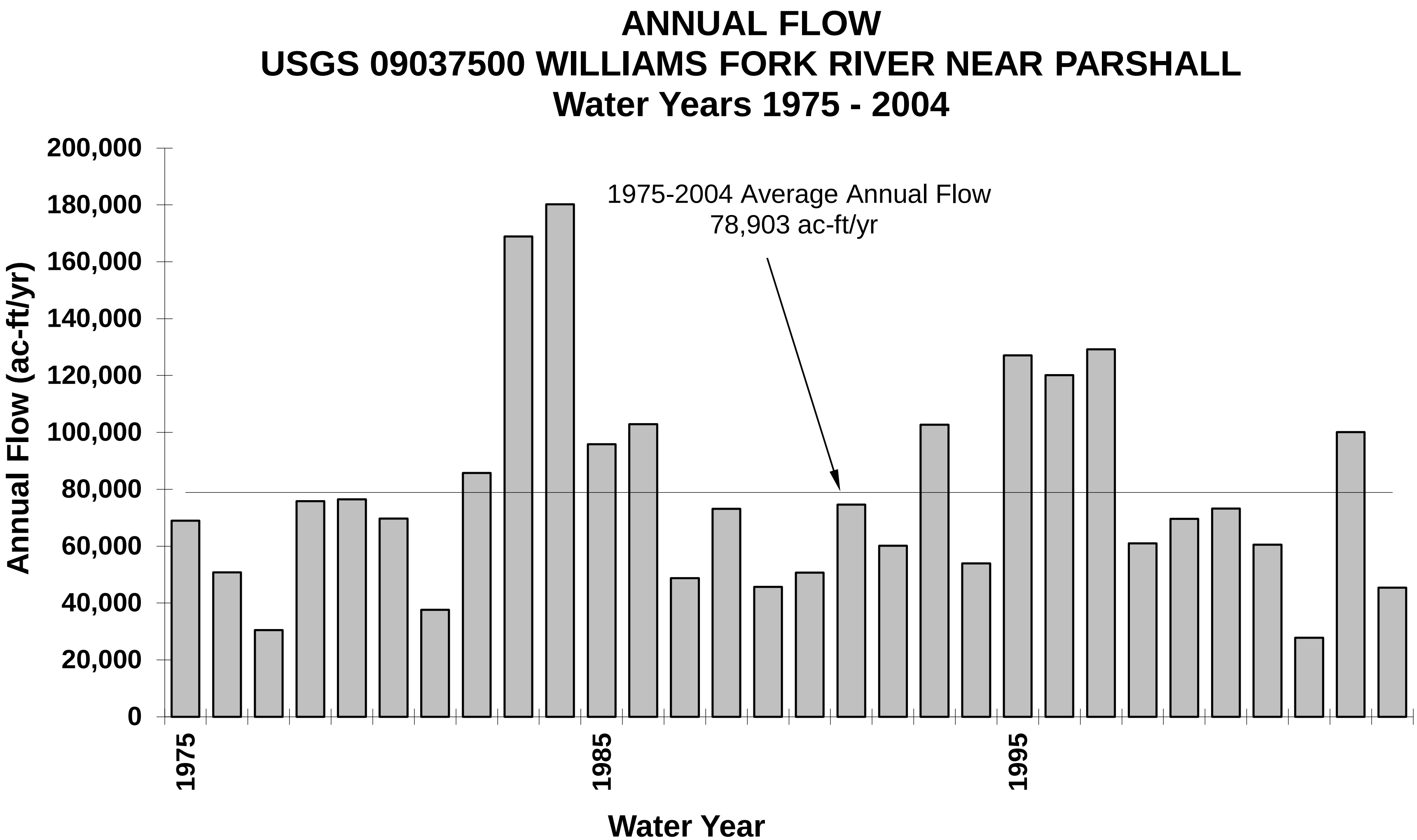

MONTHLY AVERAGE FLOW
USGS 09026500 ST. LOUIS CREEK NEAR FRASER
Water Years 1975 - 2004
Monthly Average Flow (CFS)
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

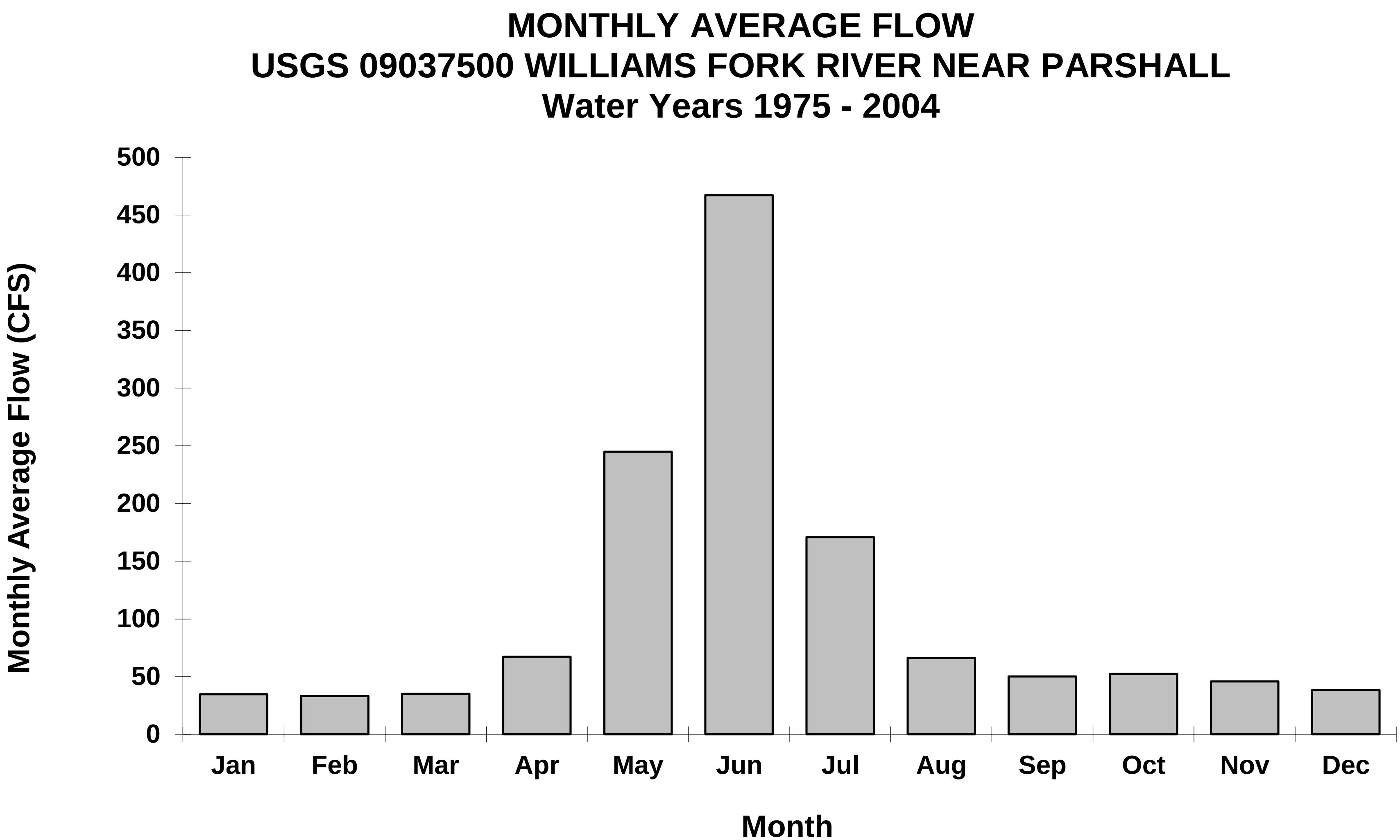

ANNUAL FLOW
USGS 09032000 RANCH CREEK NEAR FRASER
Water Years 1975 - 2004
1975-2004 Average Annual Flow
8,661 ac/ft-yr
Annual Flow (ac-ft/yr)
25,000
20,000
15,000
10,000
5,000
0
1975
1985
1995
Water Year

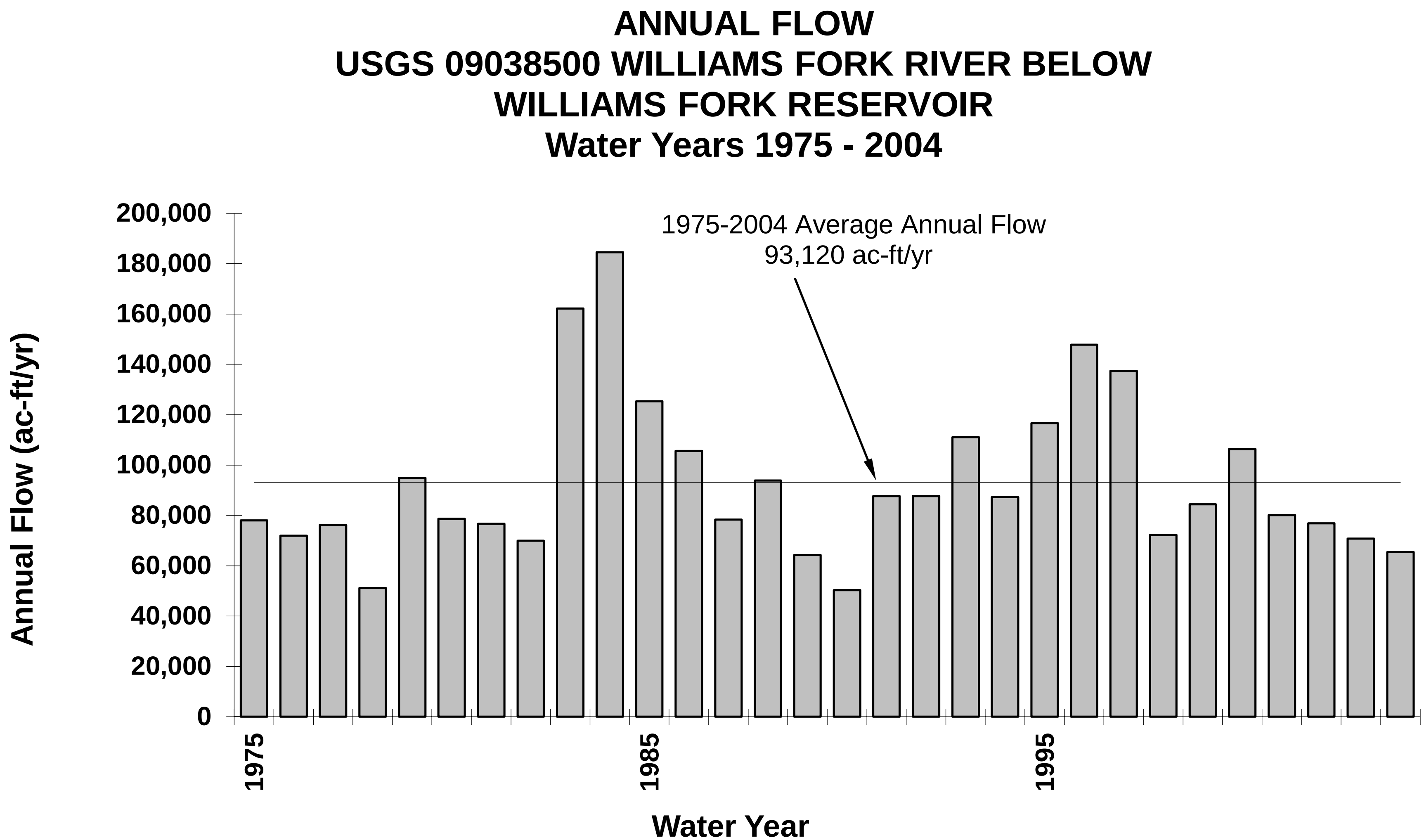

MONTHLY AVERAGE FLOW
USGS 09032000 RANCH CREEK NEAR FRASER
Water Years 1975 - 2004
Monthly Average Flow (CFS)
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

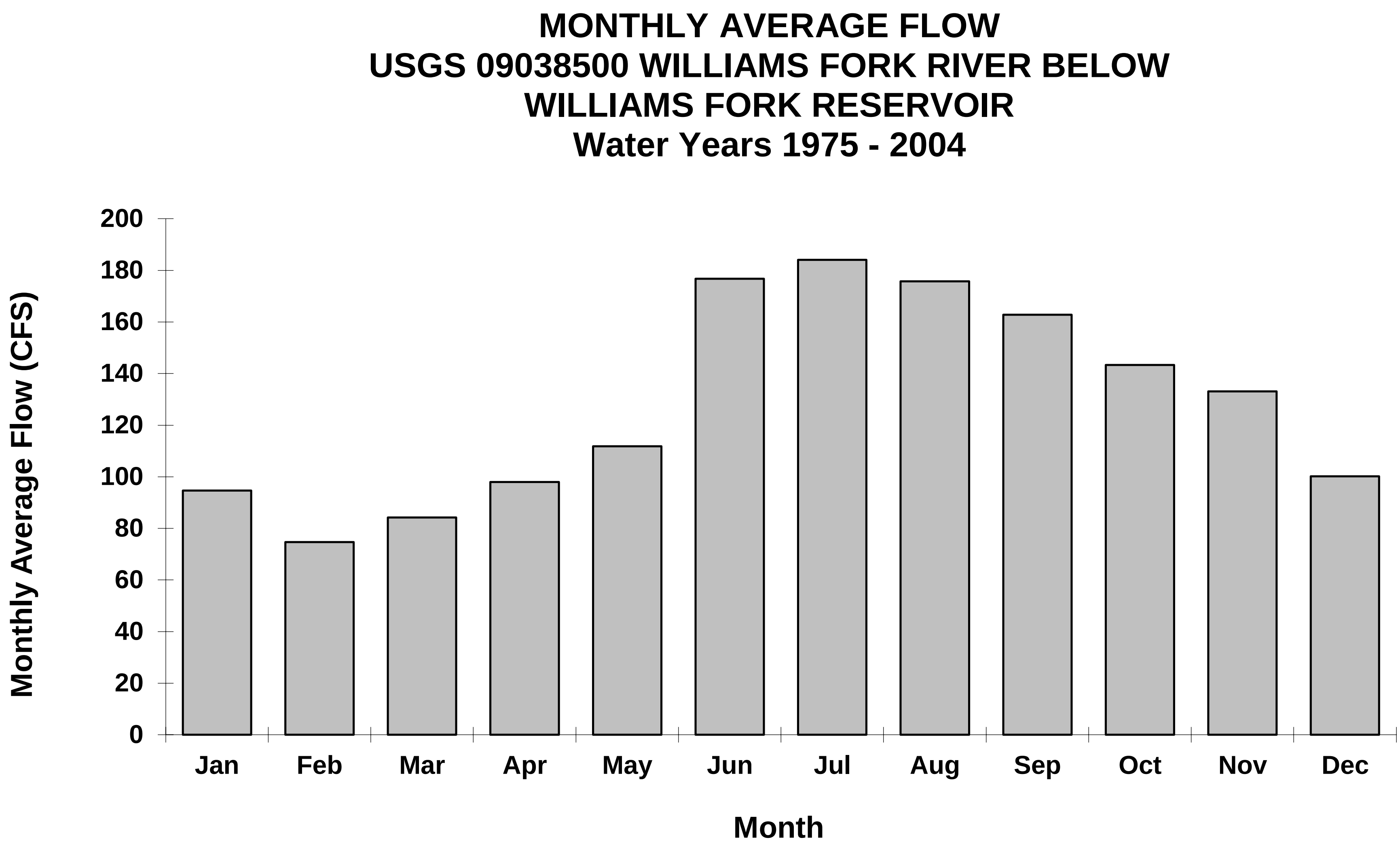

ANNUAL FLOW
USGS 09035500 WILLIAMS FORK RIVER BELOW
STEELMAN CREEK
Water Years 1975 - 2004
1975-2004 Average Annual Flow
14,080 ac-ft/yr
Annual Flow (ac-ft/yr)
30,000
25,000
20,000
15,000
10,000
5,000
0
1975
1985
1995
Water Year

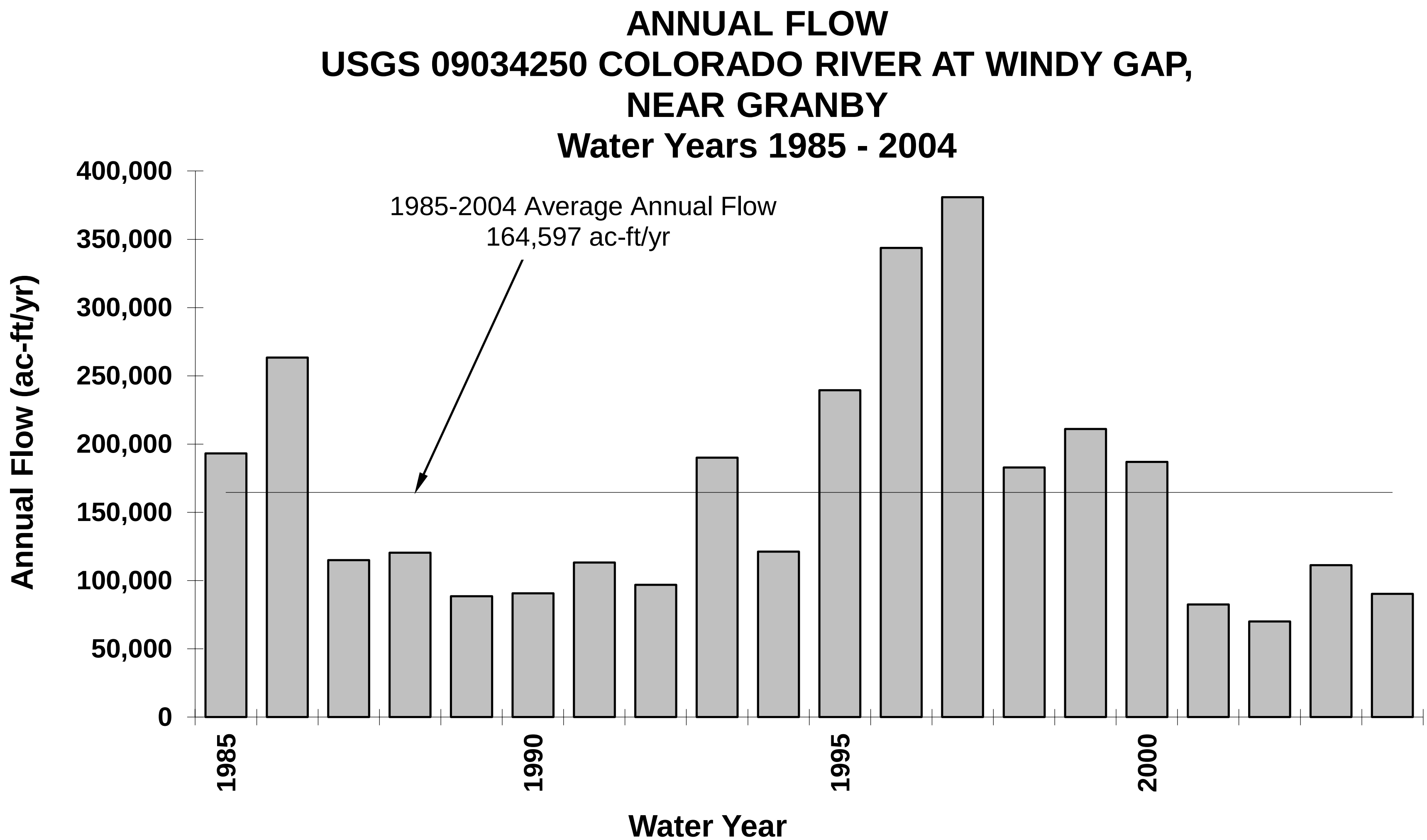

MONTHLY AVERAGE FLOW
USGS 09035500 WILLIAMS FORK RIVER BELOW STEELMAN CREEK
Water Years 1975 - 2004
Monthly Average Flow (CFS)
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

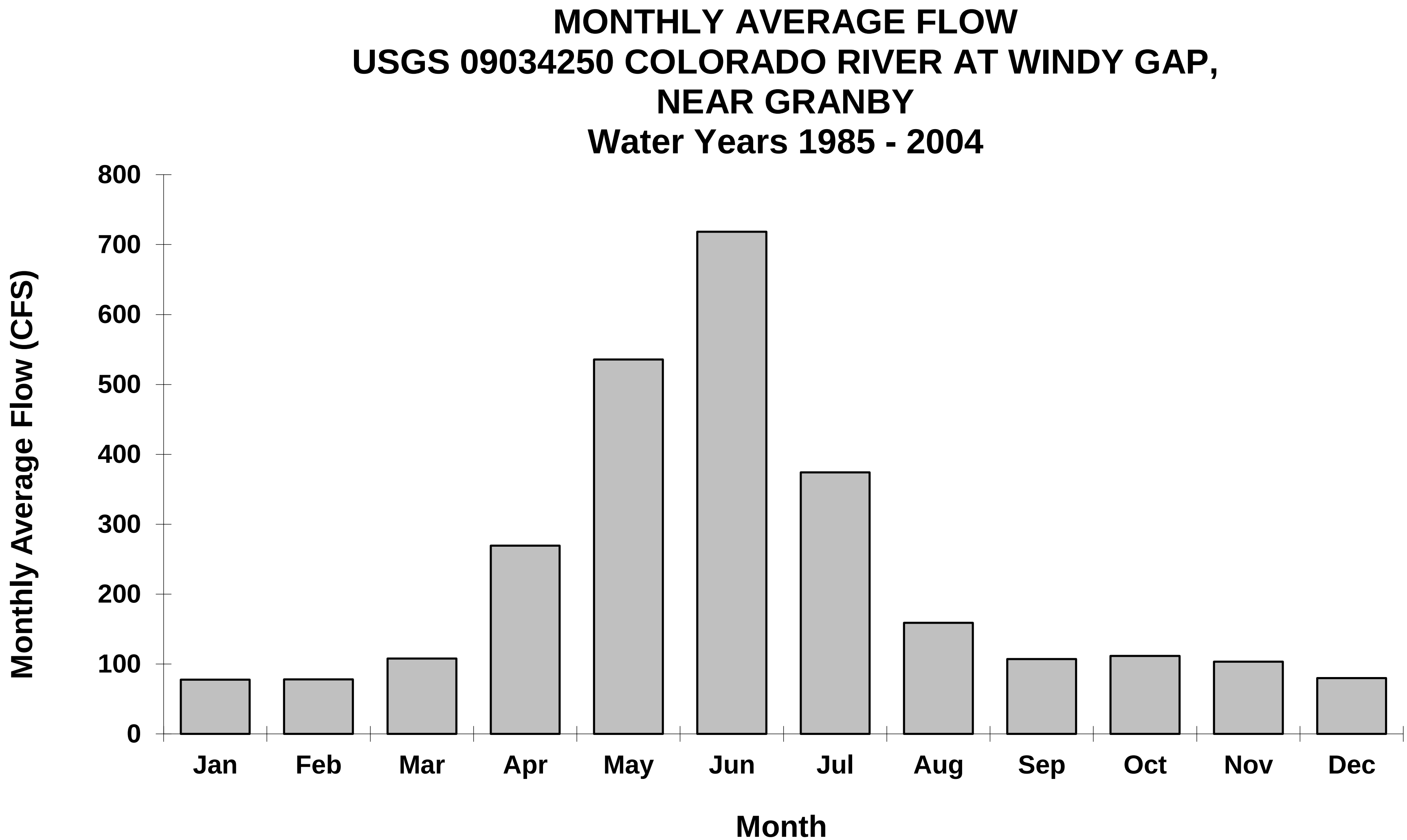

ANNUAL FLOW
USGS 09037500 WILLIAMS FORK RIVER NEAR PARSHALL
Water Years 1975 - 2004
1975-2004 Average Annual Flow
78,903 ac-ft/yr
Annual Flow (ac-ft/yr)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1975
1985
1995
Water Year

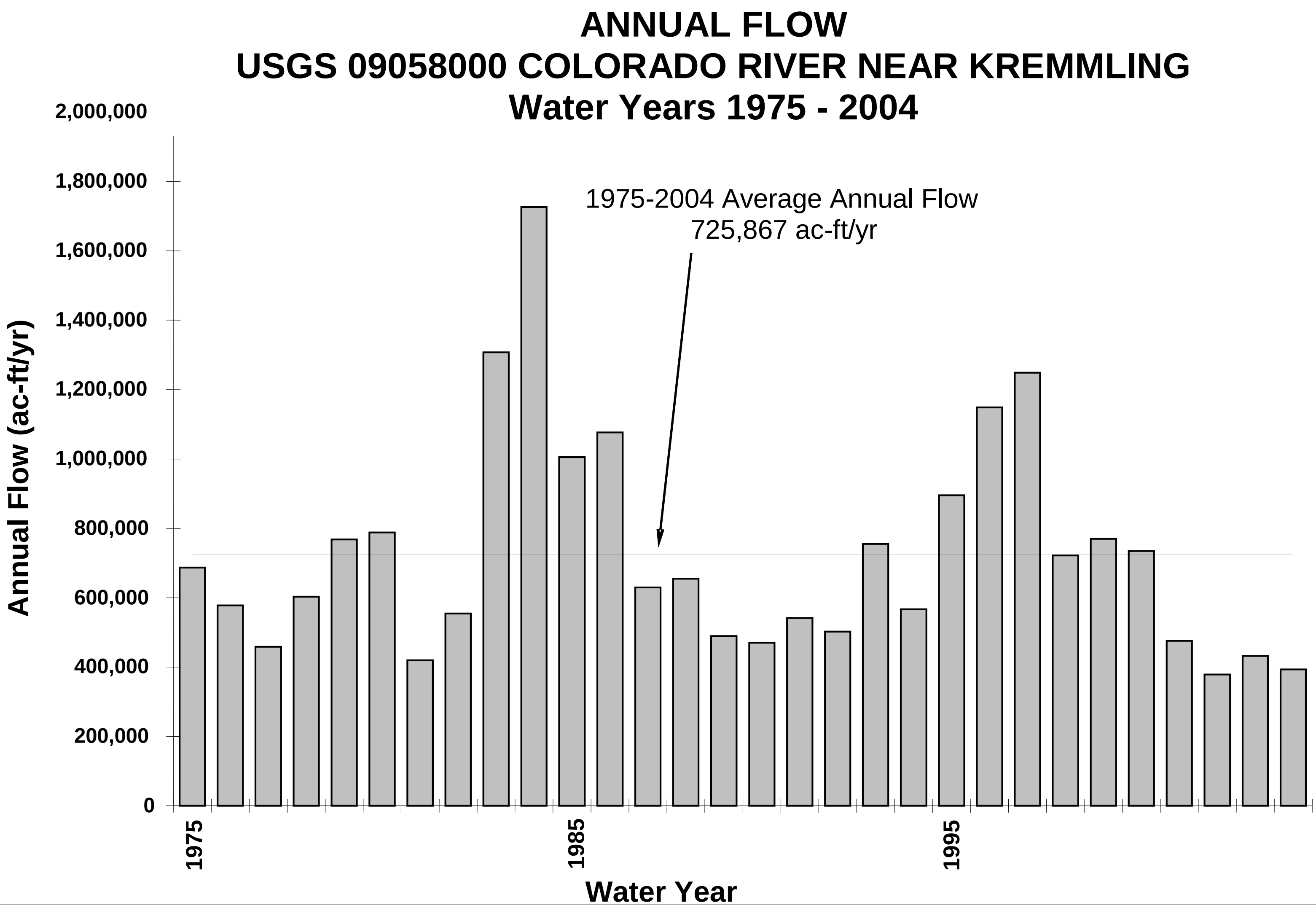

MONTHLY AVERAGE FLOW
USGS 09037500 WILLIAMS FORK RIVER NEAR PARSHALL
Water Years 1975 - 2004
Monthly Average Flow (CFS)
500
450
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

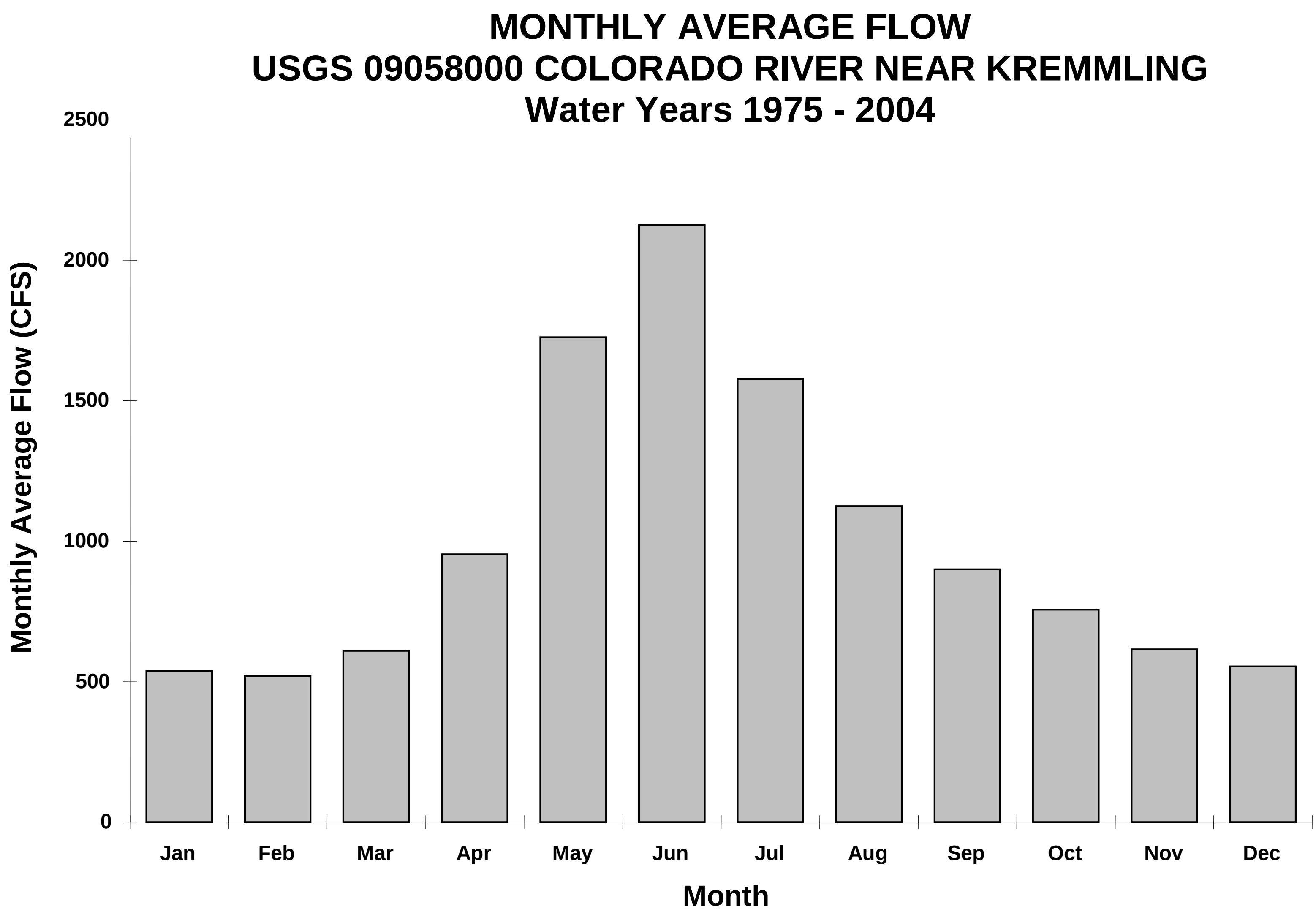

ANNUAL FLOW
USGS 09038500 WILLIAMS FORK RIVER BELOW
WILLIAMS FORK RESERVOIR
Water Years 1975 - 2004
1975-2004 Average Annual Flow
93,120 ac-ft/yr
Annual Flow (ac-ft/yr)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1975
1985
1995
Water Year

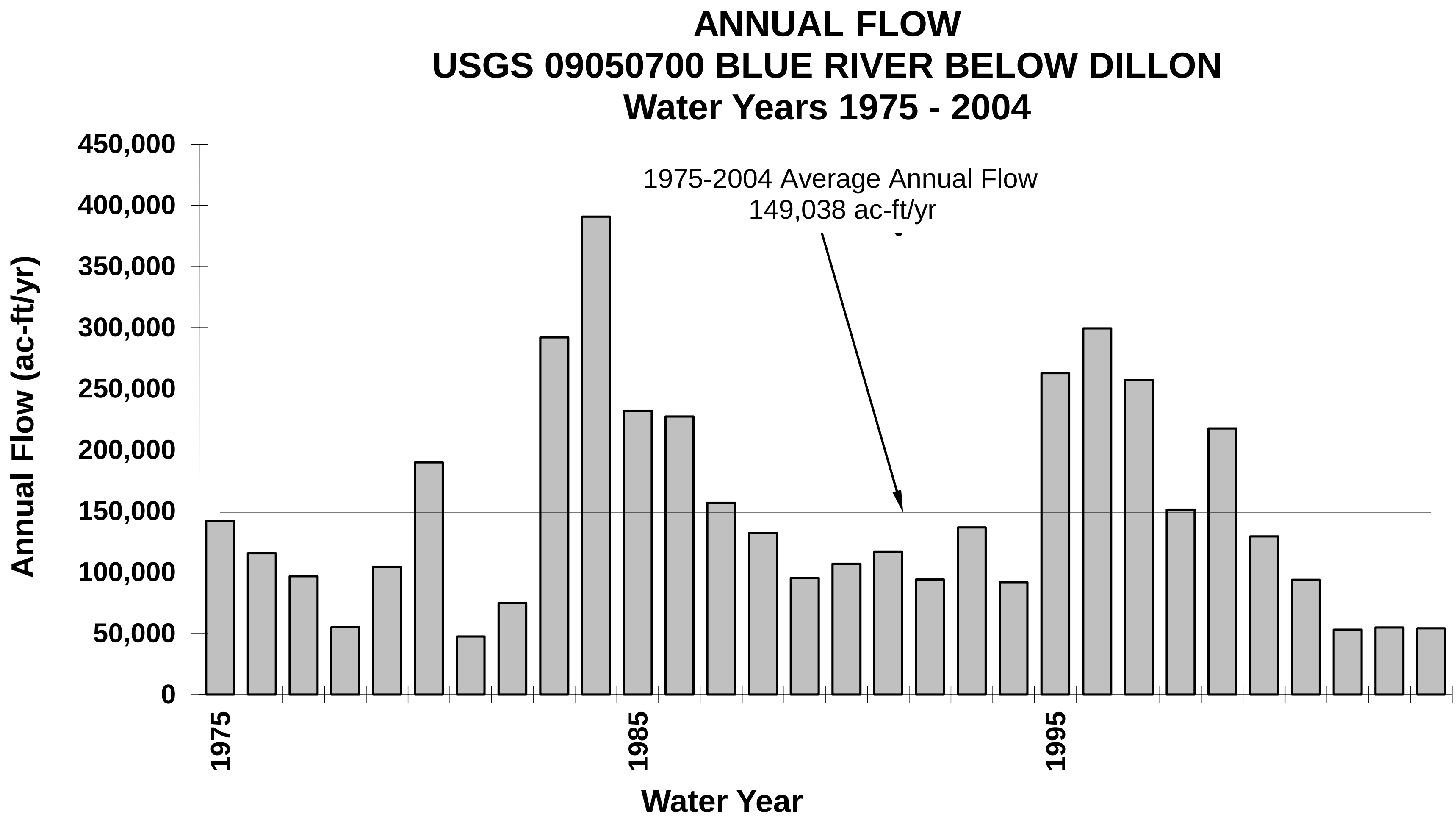

MONTHLY AVERAGE FLOW
USGS 09038500 WILLIAMS FORK RIVER BELOW
WILLIAMS FORK RESERVOIR
Water Years 1975 - 2004
Monthly Average Flow (CFS)
200
180
160
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

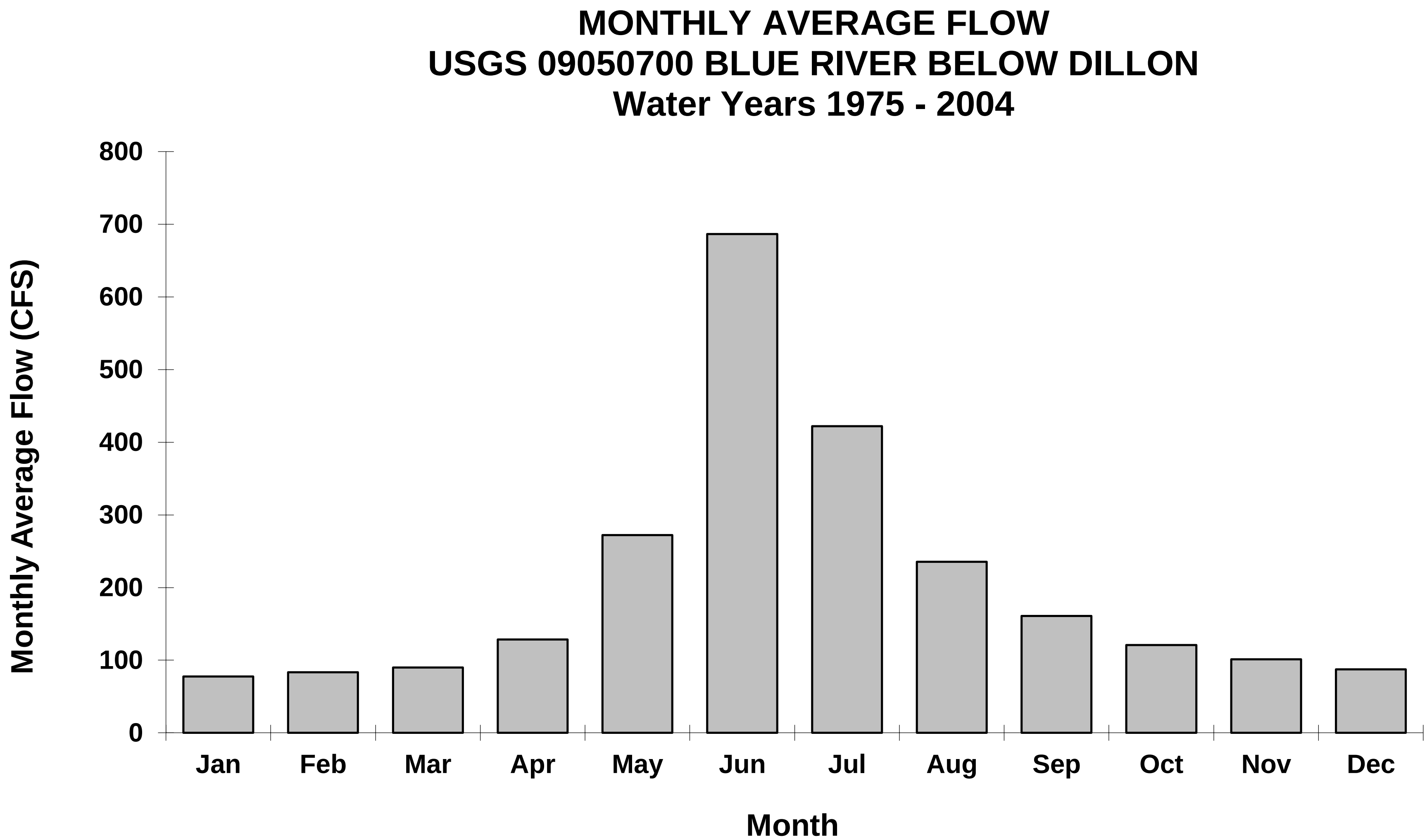

ANNUAL FLOW
USGS 09034250 COLORADO RIVER AT WINDY GAP,
NEAR GRANBY
Water Years 1985 - 2004
1985-2004 Average Annual Flow
164,597 ac-ft/yr
Annual Flow (ac-ft/yr)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1985
1990
1995
2000
Water Year


MONTHLY AVERAGE FLOW
USGS 09034250 COLORADO RIVER AT WINDY GAP,
NEAR GRANBY
Water Years 1985 - 2004
Monthly Average Flow (CFS)
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

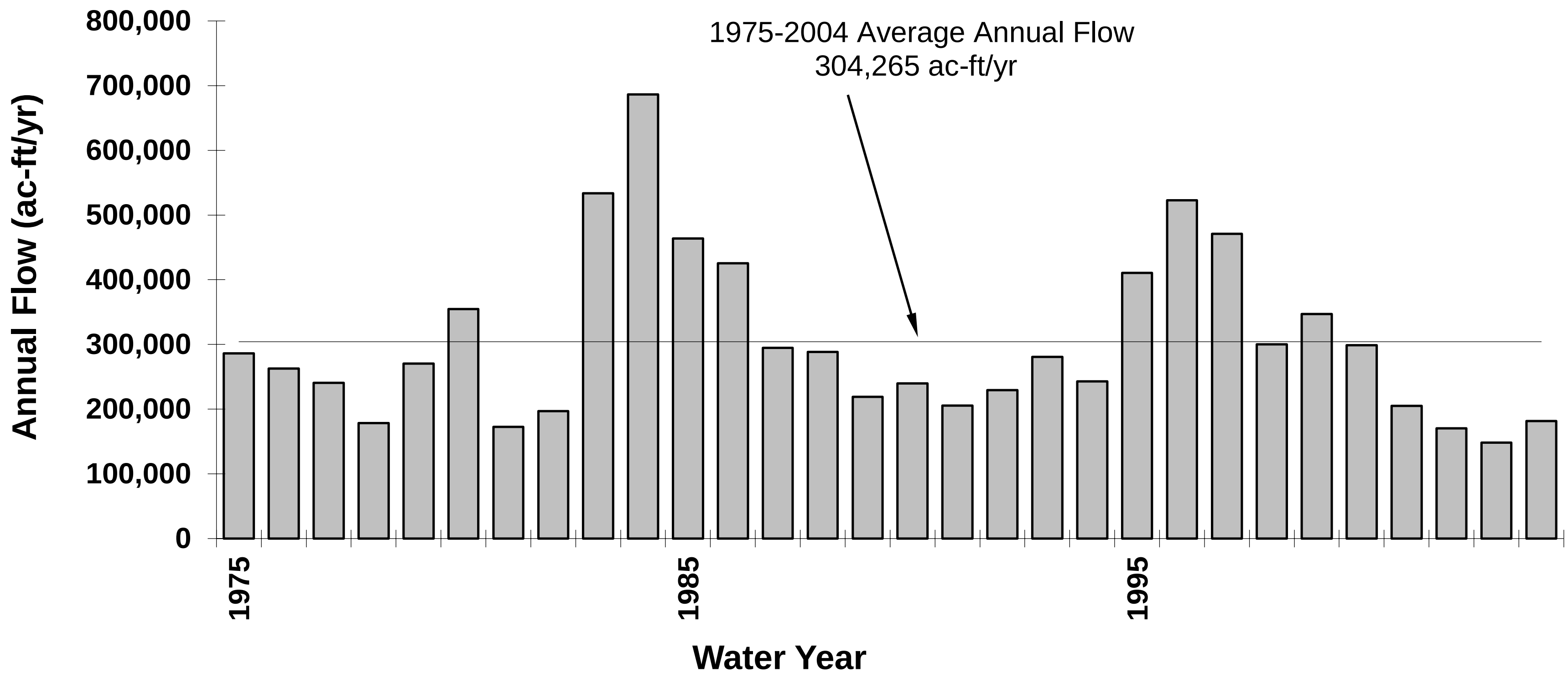

ANNUAL FLOW
USGS 09058000 COLORADO RIVER NEAR KREMMLING
Water Years 1975 - 2004
Annual Flow (ac-ft/yr)
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1975-2004 Average Annual Flow
725,867 ac-ft/yr
1975
1985
1995
Water Year

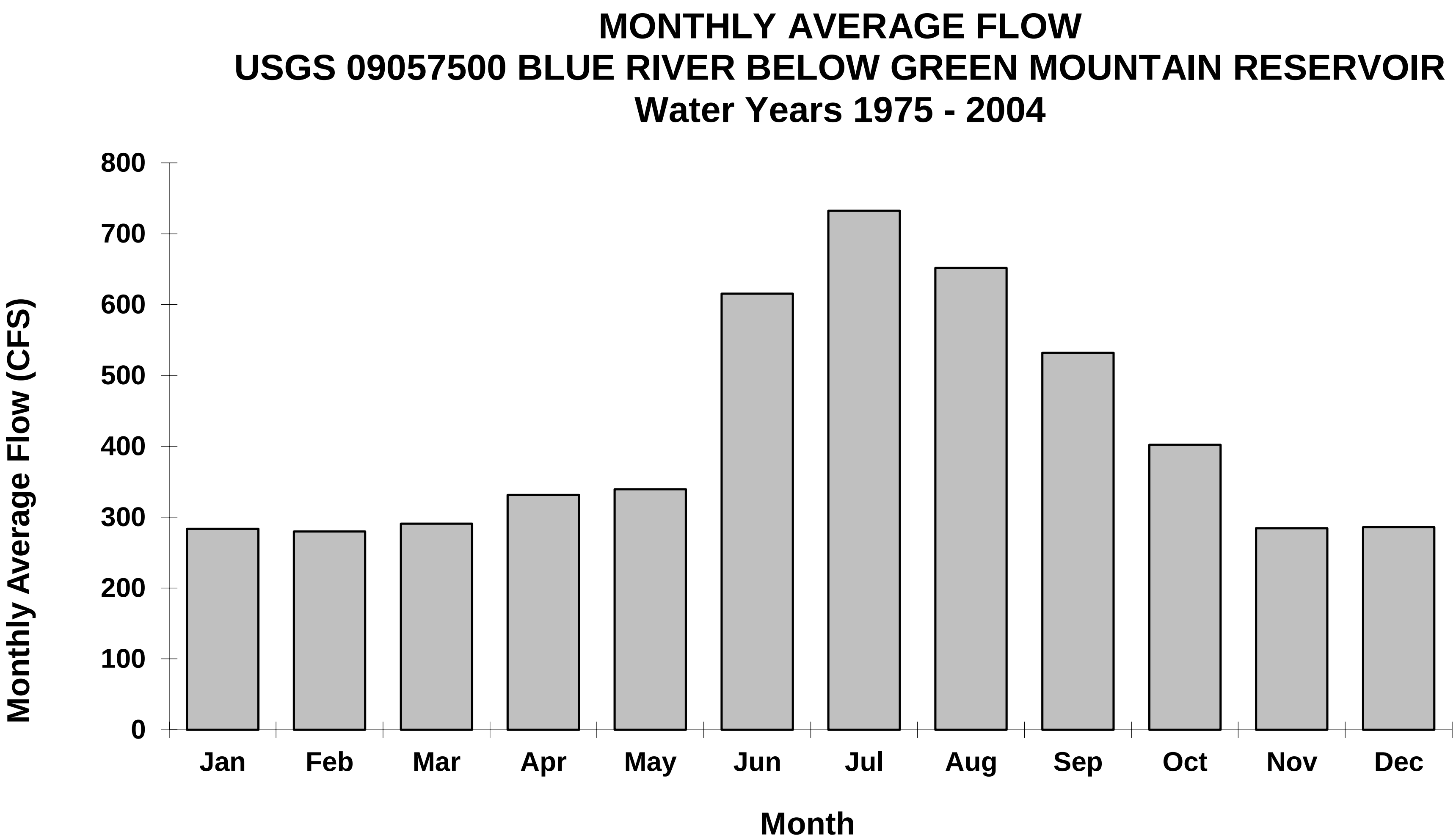

MONTHLY AVERAGE FLOW
USGS 09058000 COLORADO RIVER NEAR KREMMLING
Water Years 1975 - 2004
Monthly Average Flow (CFS)
2500
2000
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


ANNUAL FLOW
USGS 09050700 BLUE RIVER BELOW DILLON
Water Years 1975 - 2004
1975-2004 Average Annual Flow
149,038 ac-ft/yr
Annual Flow (ac-ft/yr)
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1975
1985
1995
Water Year


MONTHLY AVERAGE FLOW
USGS 09050700 BLUE RIVER BELOW DILLON
Water Years 1975 - 2004
Monthly Average Flow (CFS)
0
100
200
300
400
500
600
700
800
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

ANNUAL FLOW
USGS 09057500 BLUE RIVER BELOW GREEN MOUNTAIN RESERVOIR
Water Years 1975 - 2004




MONTHLY AVERAGE FLOW
USGS 09057500 BLUE RIVER BELOW GREEN MOUNTAIN RESERVOIR
Water Years 1975 - 2004
Monthly Average Flow (CFS)
0
100
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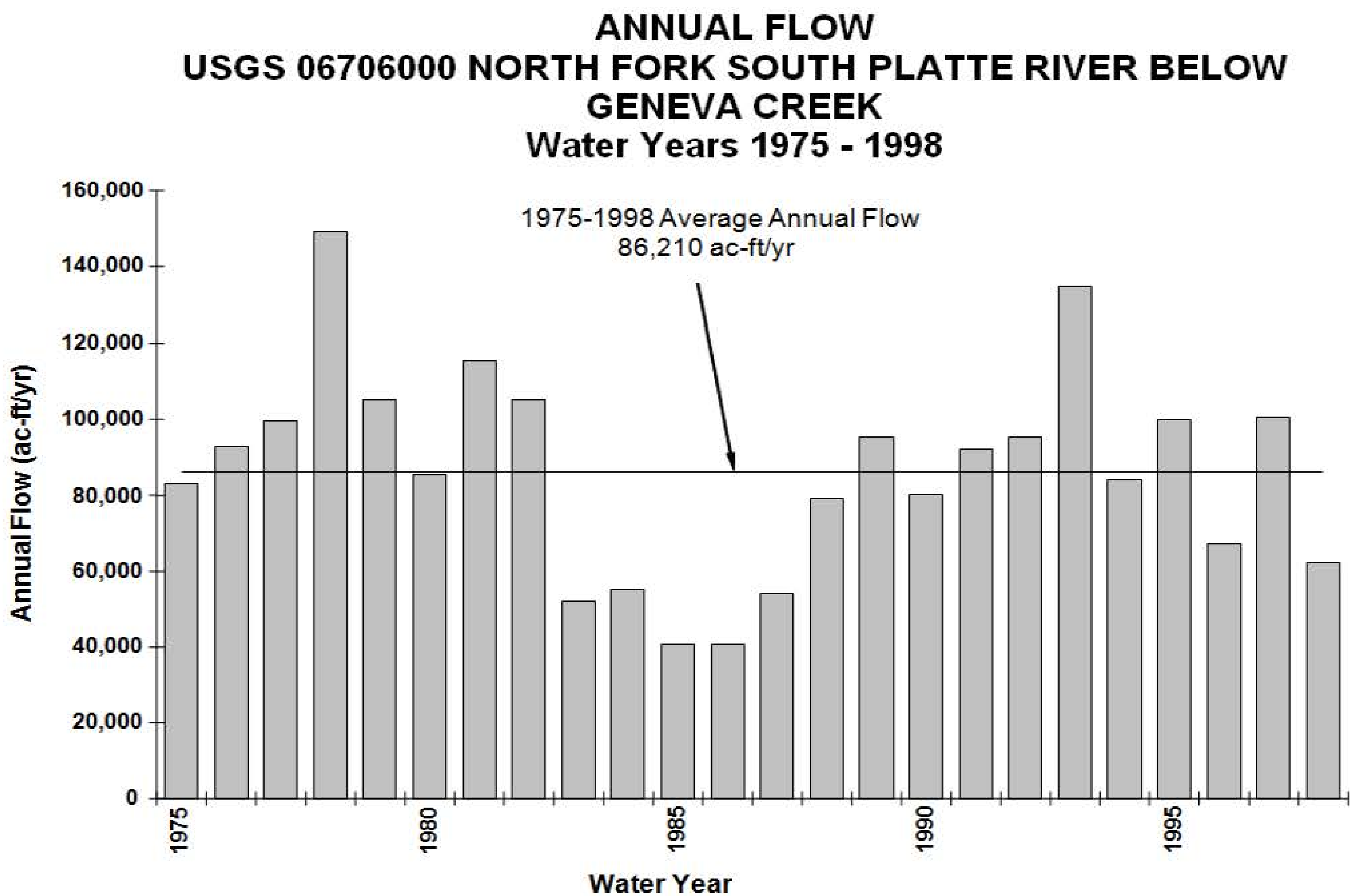
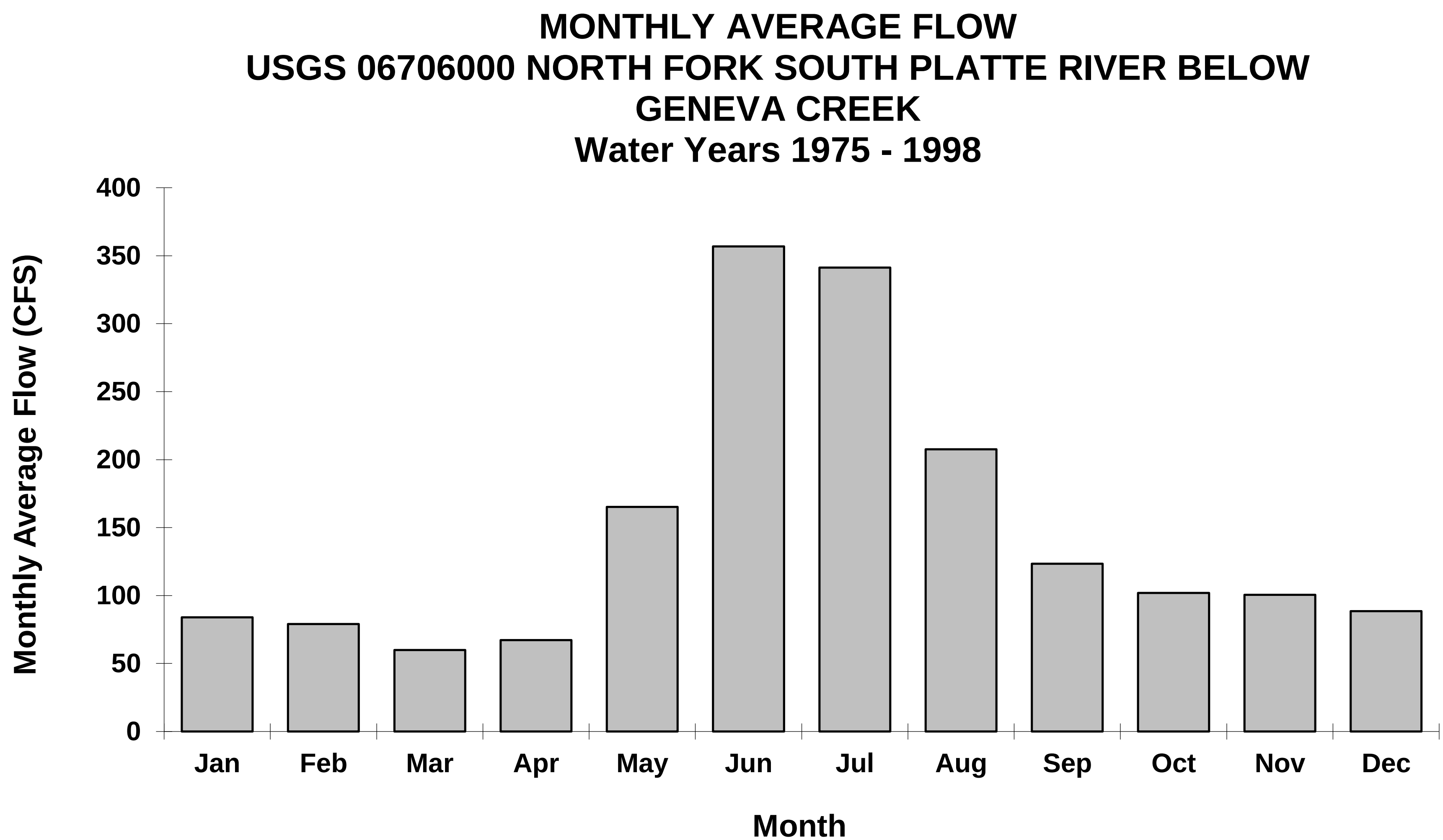
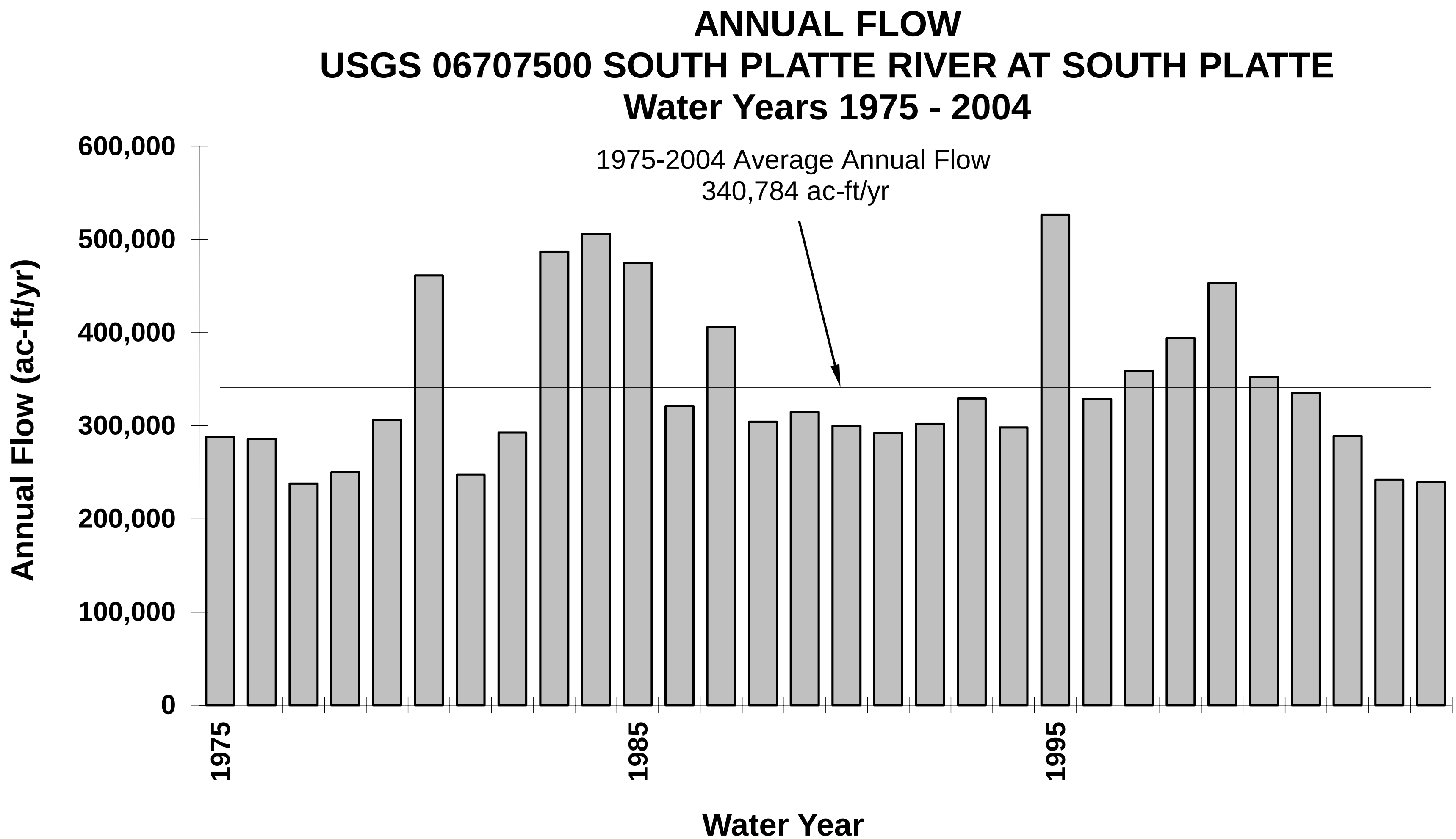
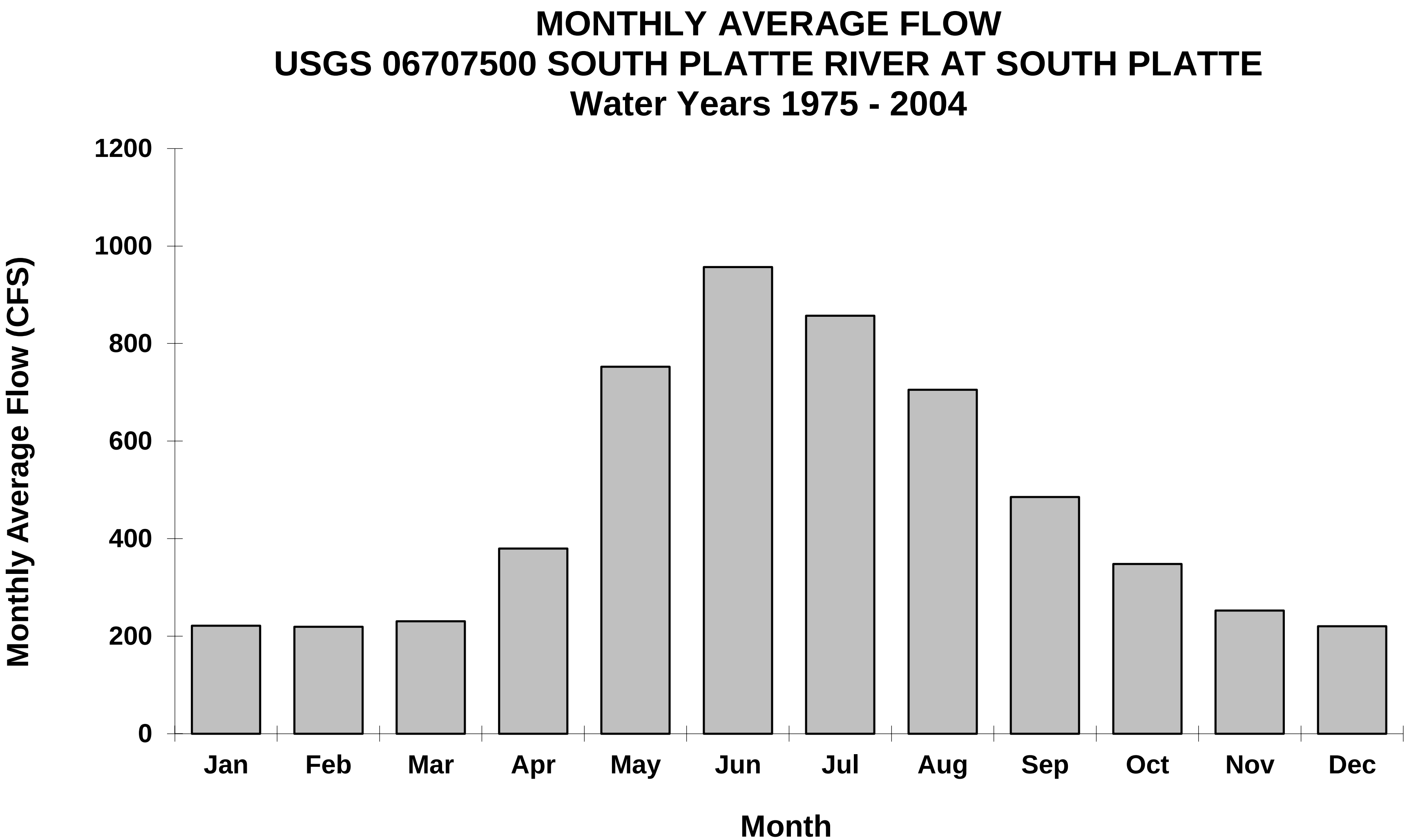
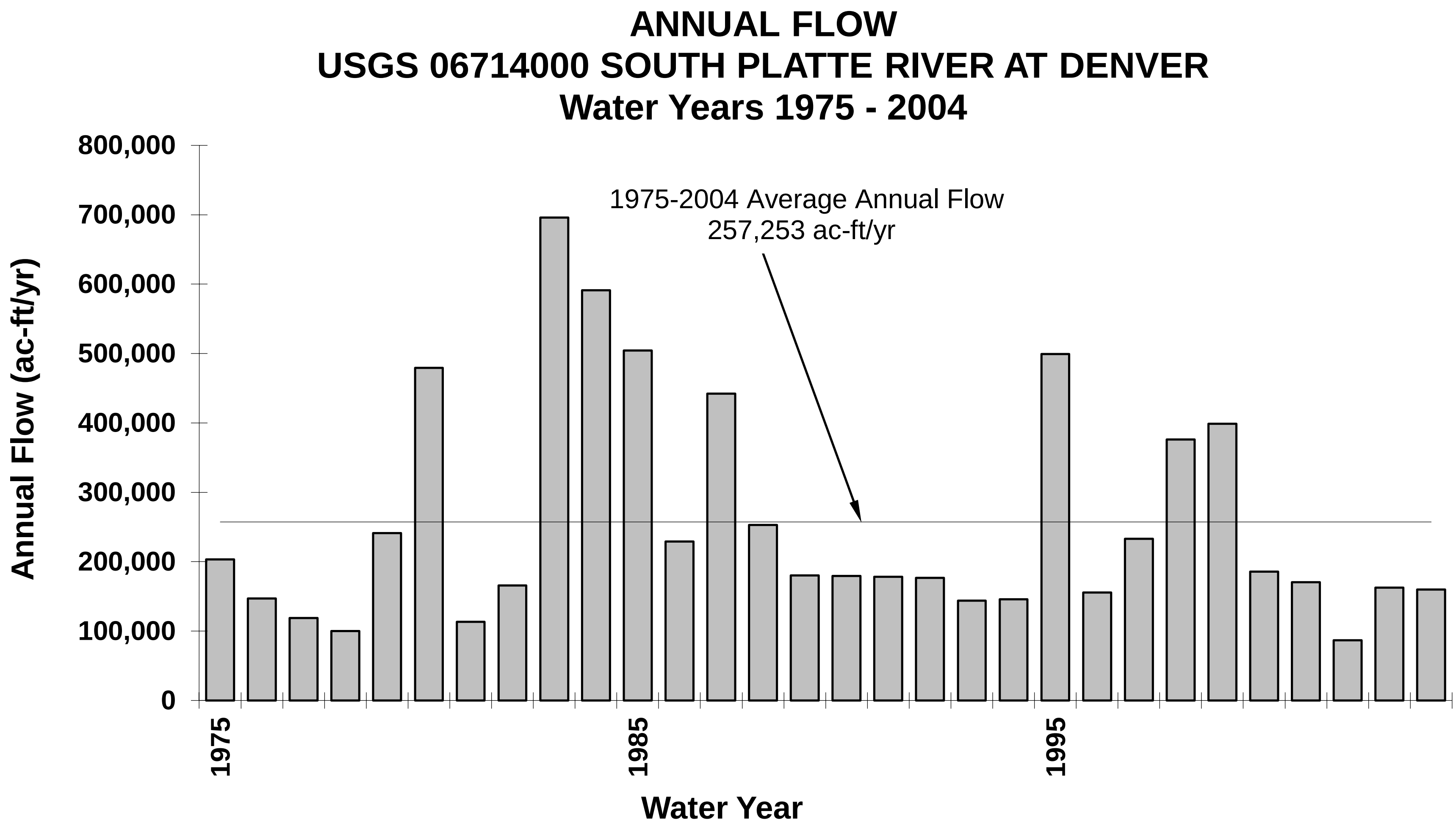
300
400
500
600
700
800
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

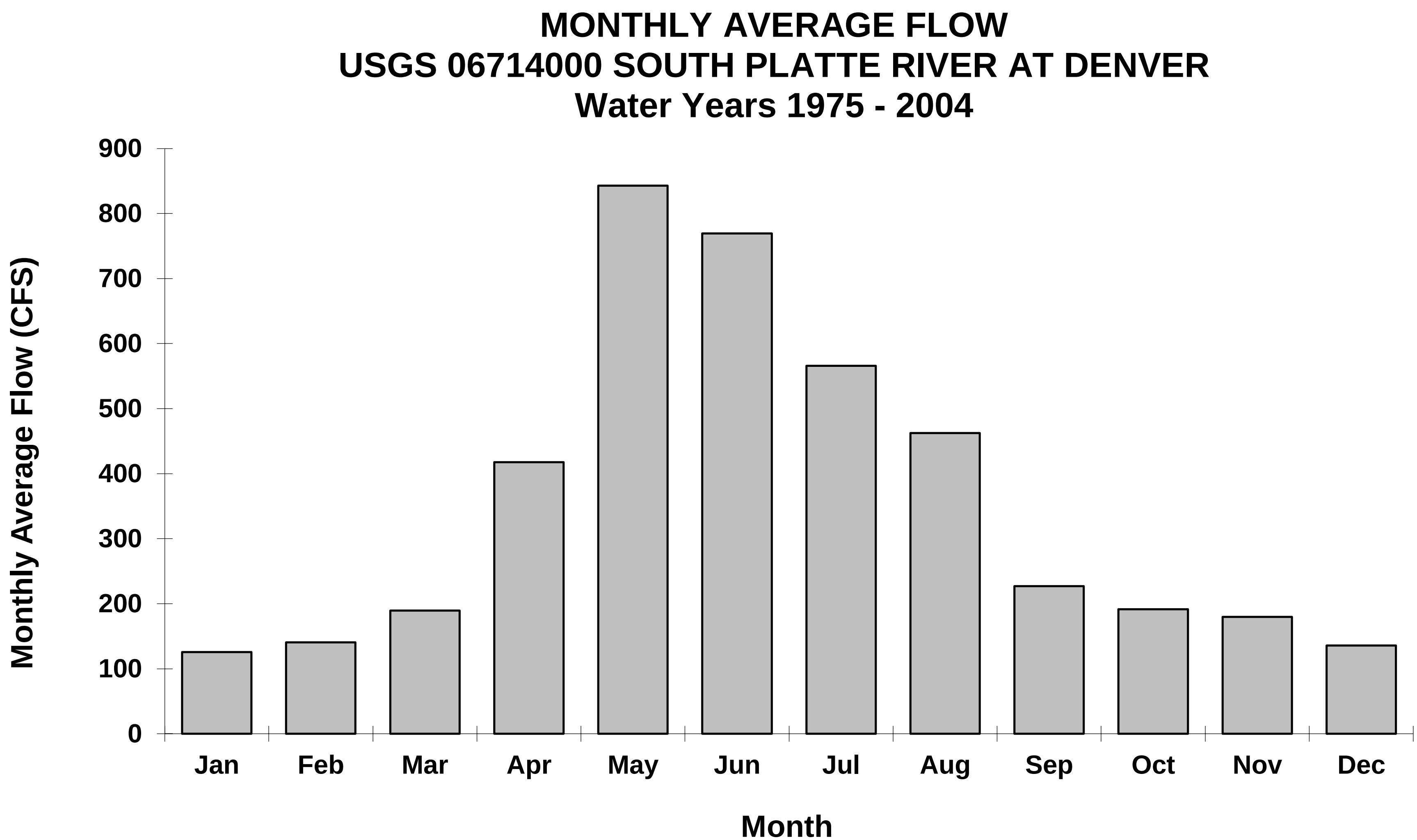

ANNUAL FLOW
USGS 06706000 NORTH FORK SOUTH PLATTE RIVER BELOW GENEVA CREEK
Water Years 1975 - 1998
1975-1998 Average Annual Flow
86,210 ac-ft/yr
Annual Flow (ac-ft/yr)
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1975
1980
1985
1990
1995
Water Year

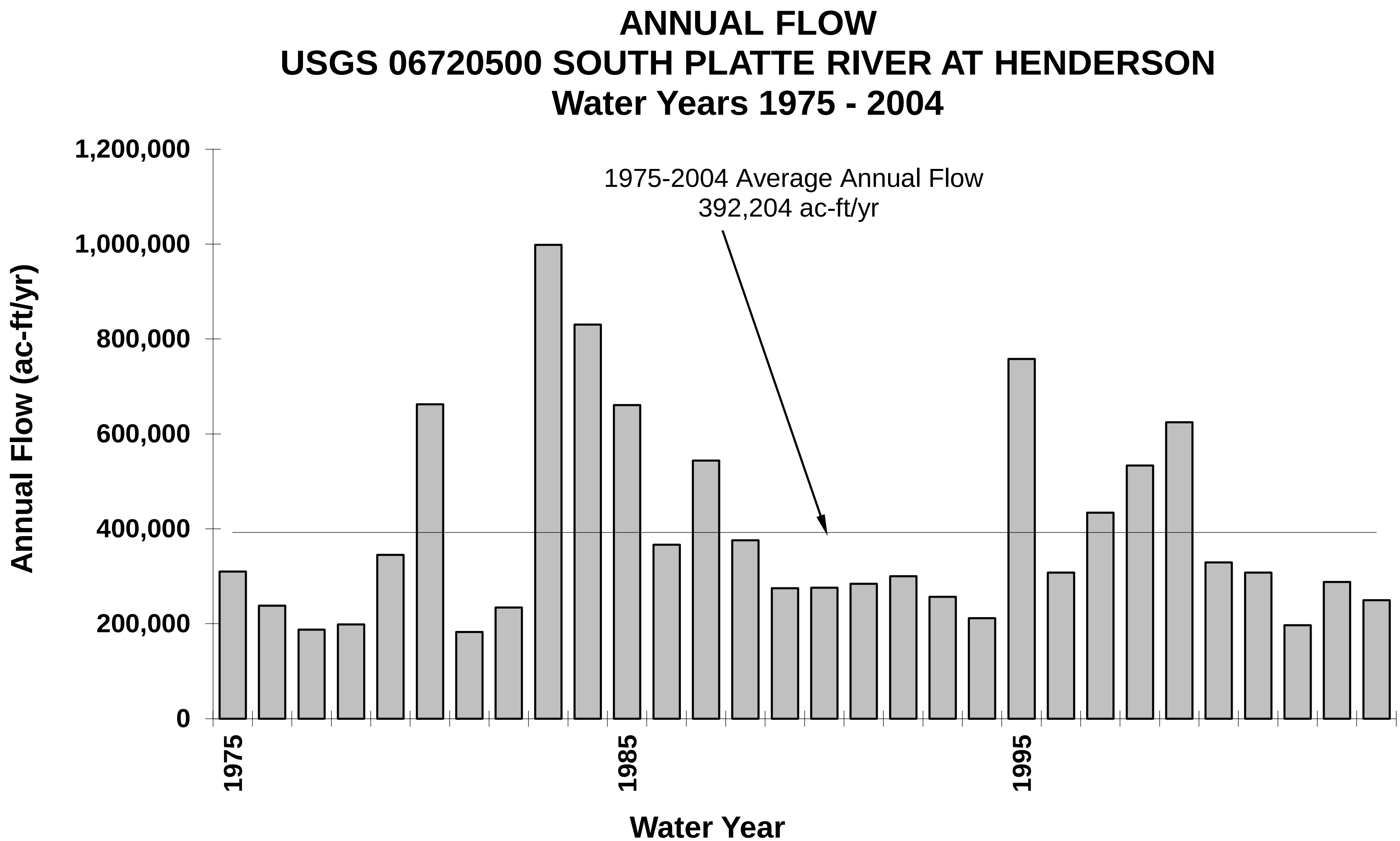

MONTHLY AVERAGE FLOW
USGS 06706000 NORTH FORK SOUTH PLATTE RIVER BELOW
GENEVA CREEK
Water Years 1975 - 1998
Monthly Average Flow (CFS)
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

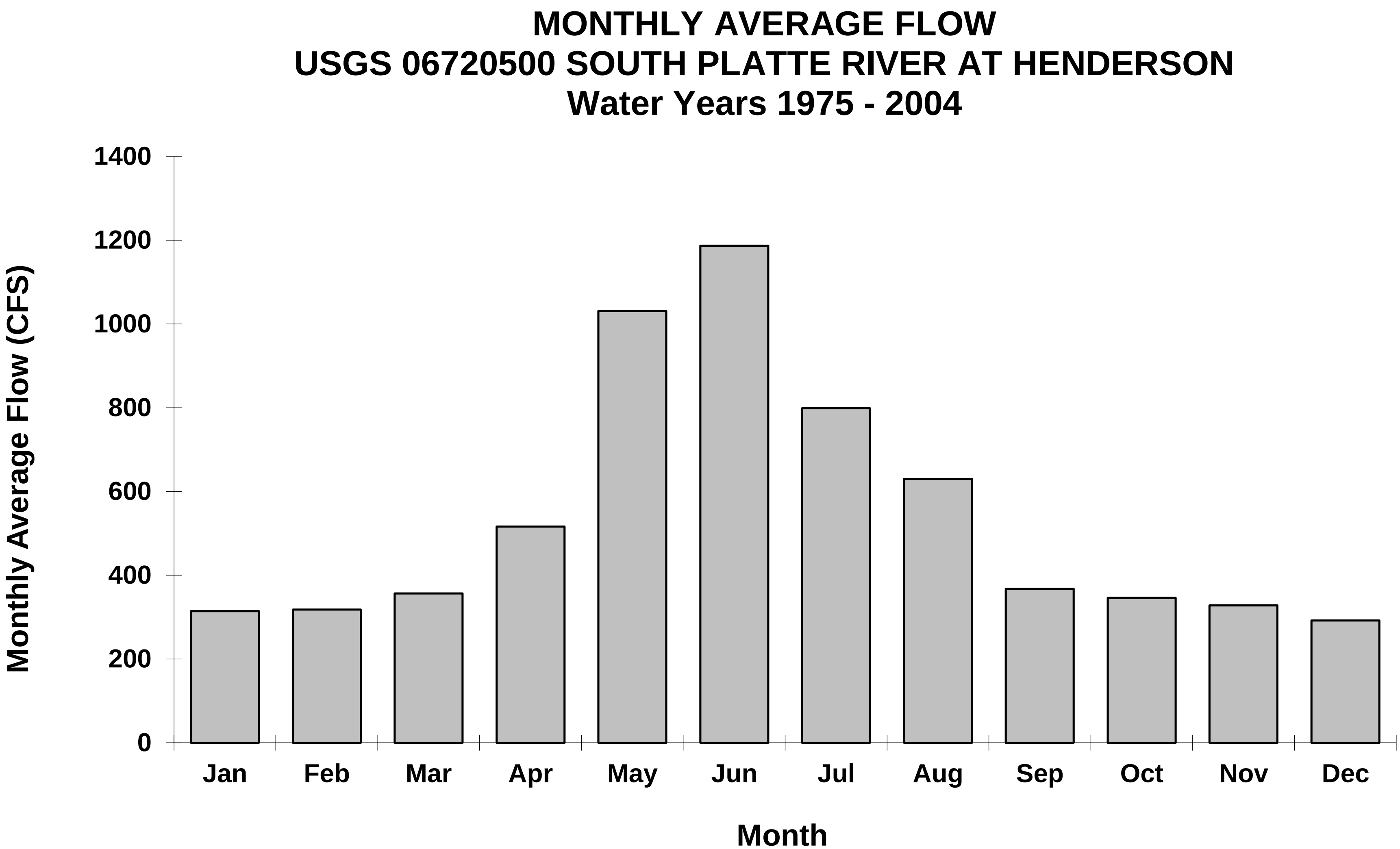

ANNUAL FLOW
USGS 06707500 SOUTH PLATTE RIVER AT SOUTH PLATTE
Water Years 1975 - 2004
1975-2004 Average Annual Flow
340,784 ac-ft/yr
600,000
500,000
400,000
300,000
200,000
100,000
0
Annual Flow (ac-ft/yr)
1975
1985
1995
Water Year


MONTHLY AVERAGE FLOW
USGS 06707500 SOUTH PLATTE RIVER AT SOUTH PLATTE
Water Years 1975 - 2004
Monthly Average Flow (CFS)
1200
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


ANNUAL FLOW
USGS 06714000 SOUTH PLATTE RIVER AT DENVER
Water Years 1975 - 2004
1975-2004 Average Annual Flow
257,253 ac-ft/yr
Annual Flow (ac-ft/yr)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1975
1985
1995
Water Year


MONTHLY AVERAGE FLOW
USGS 06714000 SOUTH PLATTE RIVER AT DENVER
Water Years 1975 - 2004
Monthly Average Flow (CFS)
900
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


ANNUAL FLOW
USGS 06720500 SOUTH PLATTE RIVER AT HENDERSON
Water Years 1975 - 2004
1975-2004 Average Annual Flow
392,204 ac-ft/yr
Annual Flow (ac-ft/yr)
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1975
1985
1995
Water Year


MONTHLY AVERAGE FLOW
USGS 06720500 SOUTH PLATTE RIVER AT HENDERSON
Water Years 1975 - 2004
Monthly Average Flow (CFS)
0
200
400
600
800
1000
1200
1400
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Appendix E-3
Photographs of Stream Channel Conditions

Page

Figures:

Photographs of Representative Reaches, Existing Conditions:

Figure E-3.1: Fraser River Watershed Map with Assessment Locations

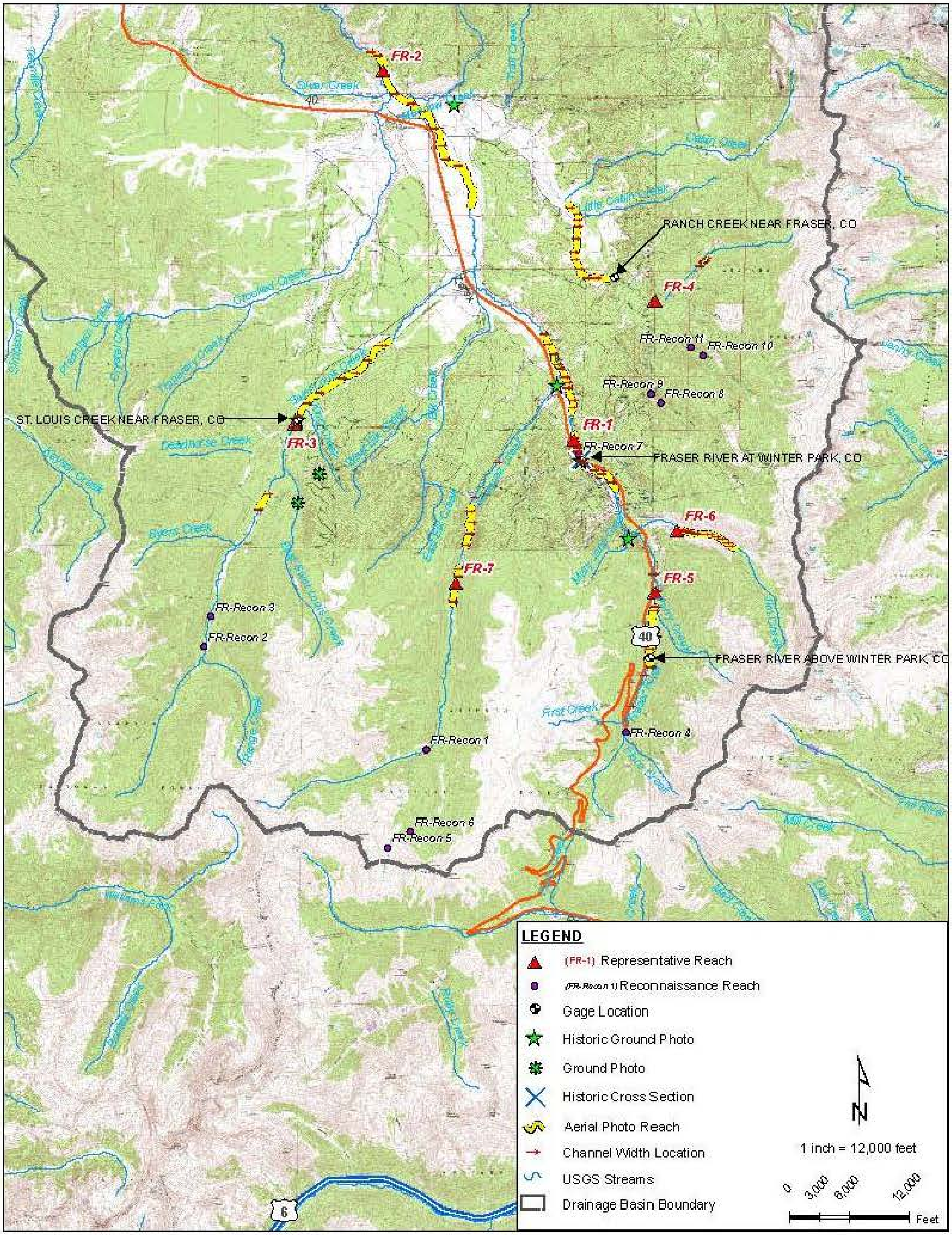


Figure E-3.2: Williams Fork River Watershed Map with Assessment Locations

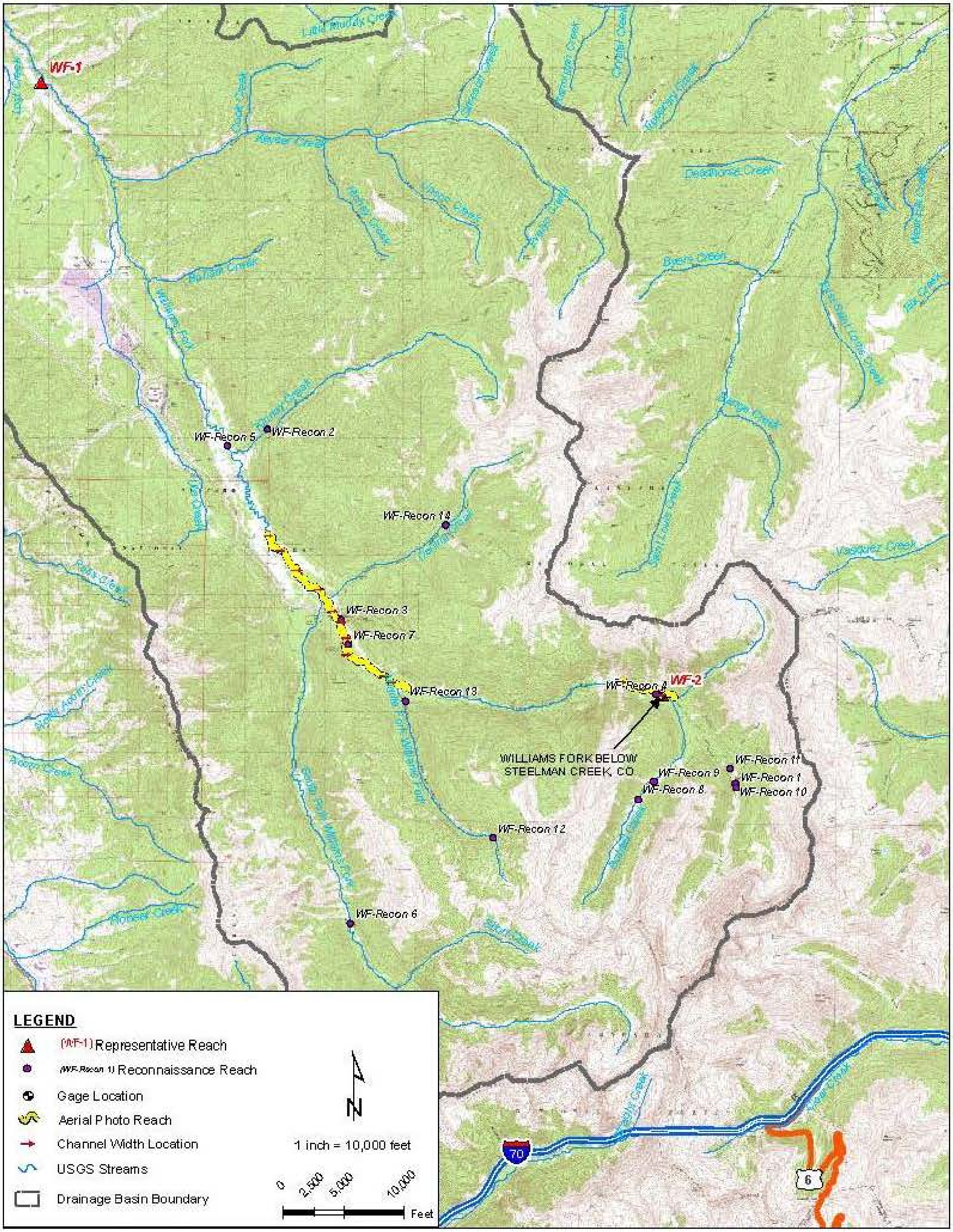


Figure E-3.3: Colorado River Watershed Map with Assessment Locations

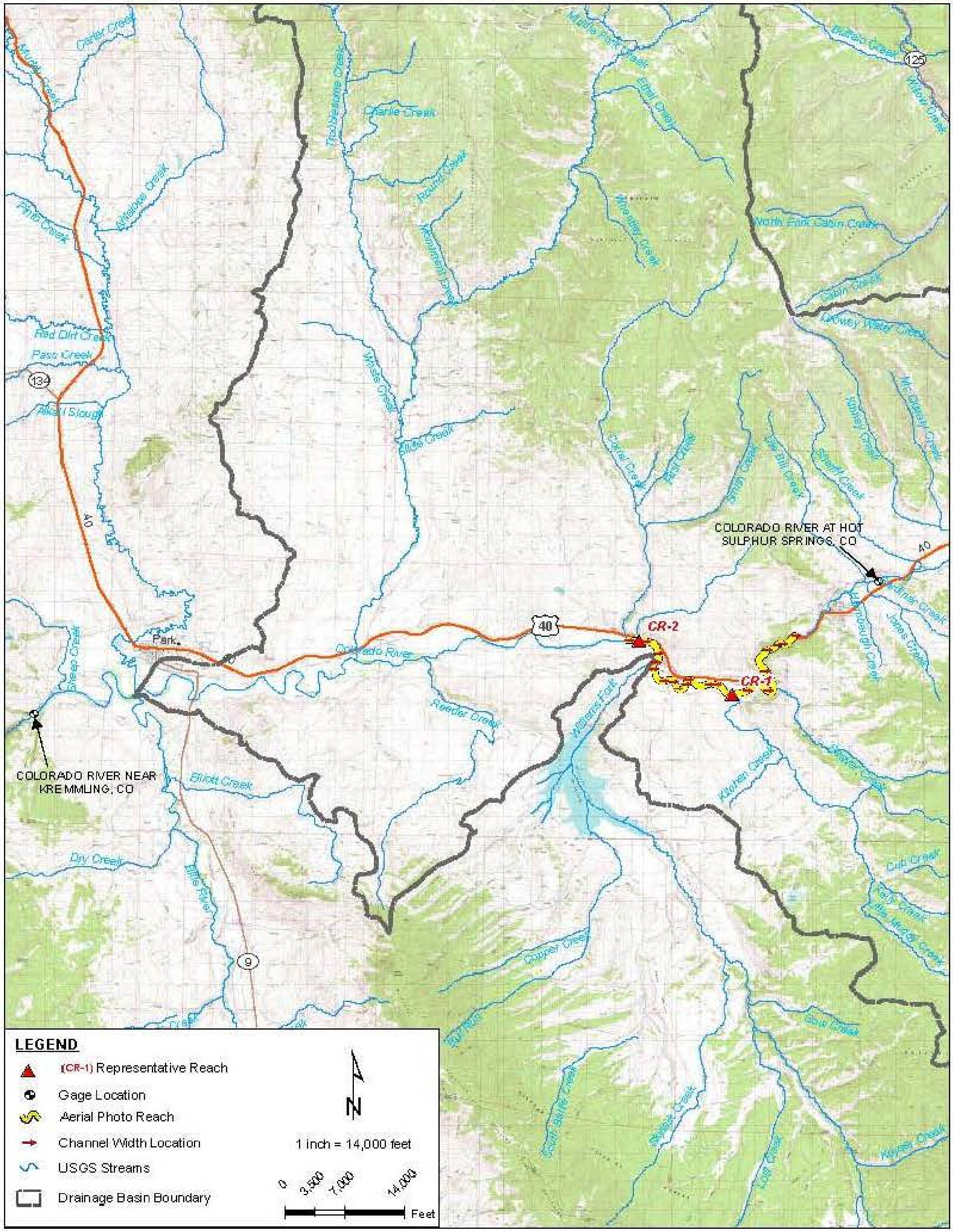


Figure E-3.4: Blue River Watershed Map with Assessment Locations

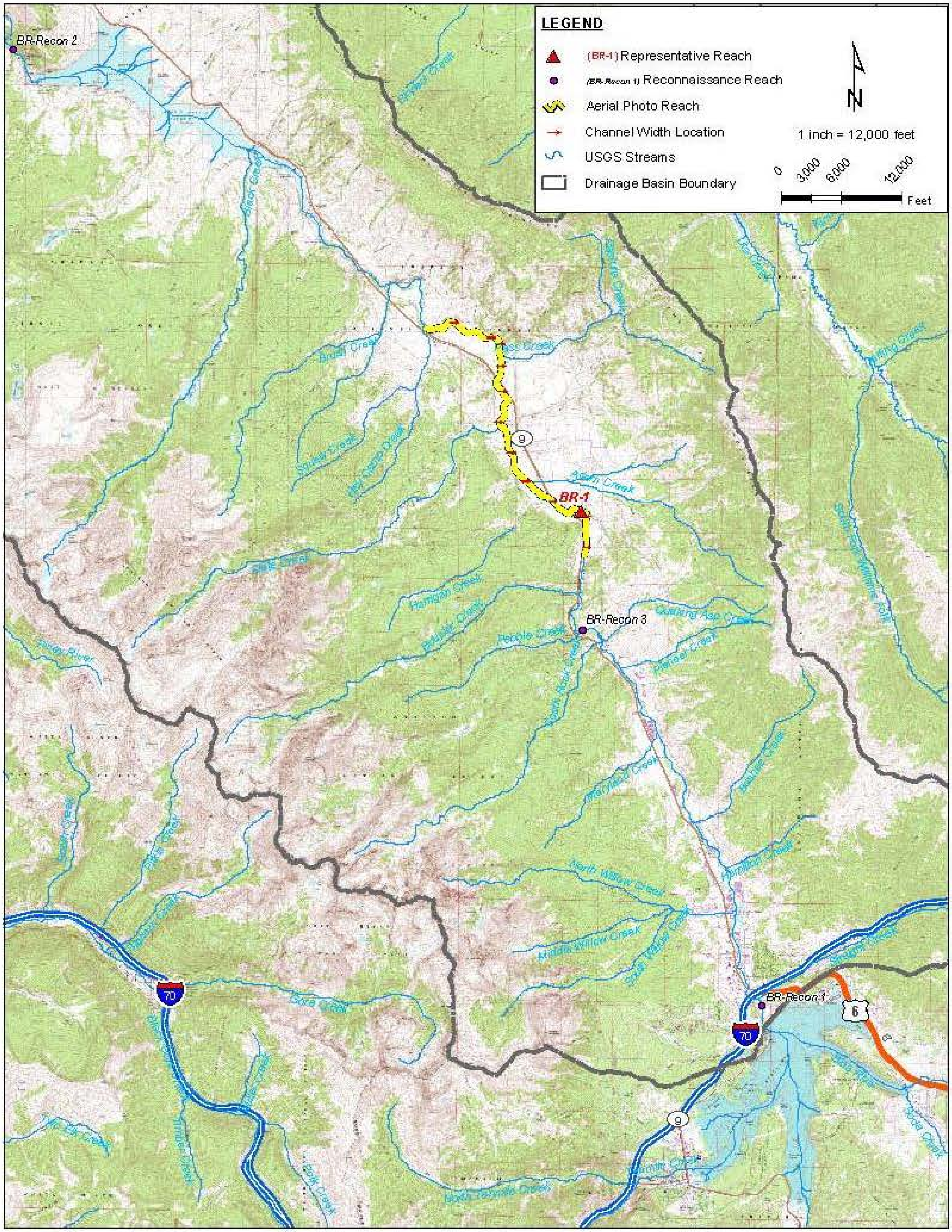


Figure E-3.5: North Fork South Platte River Watershed Map with Assessment Locations

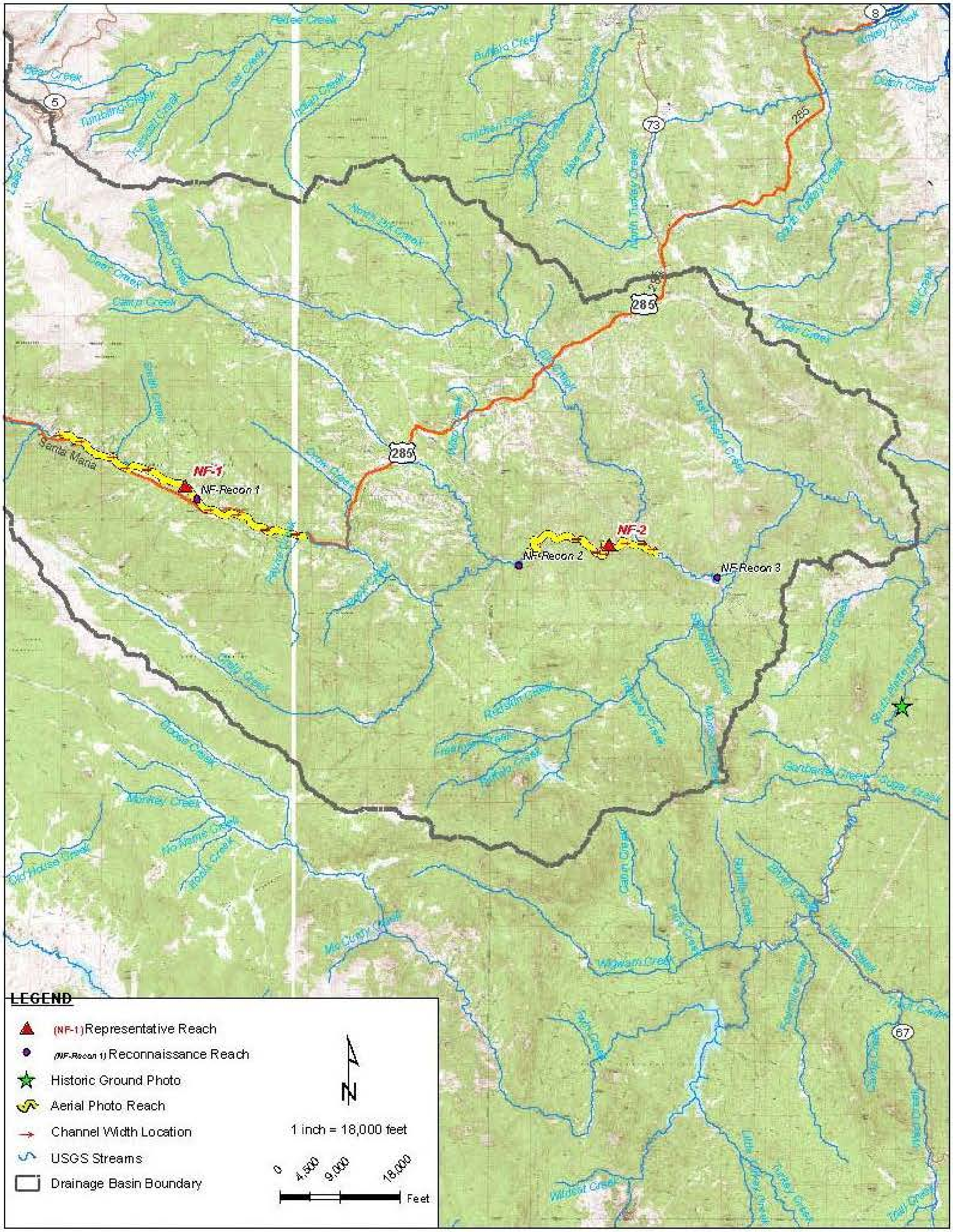
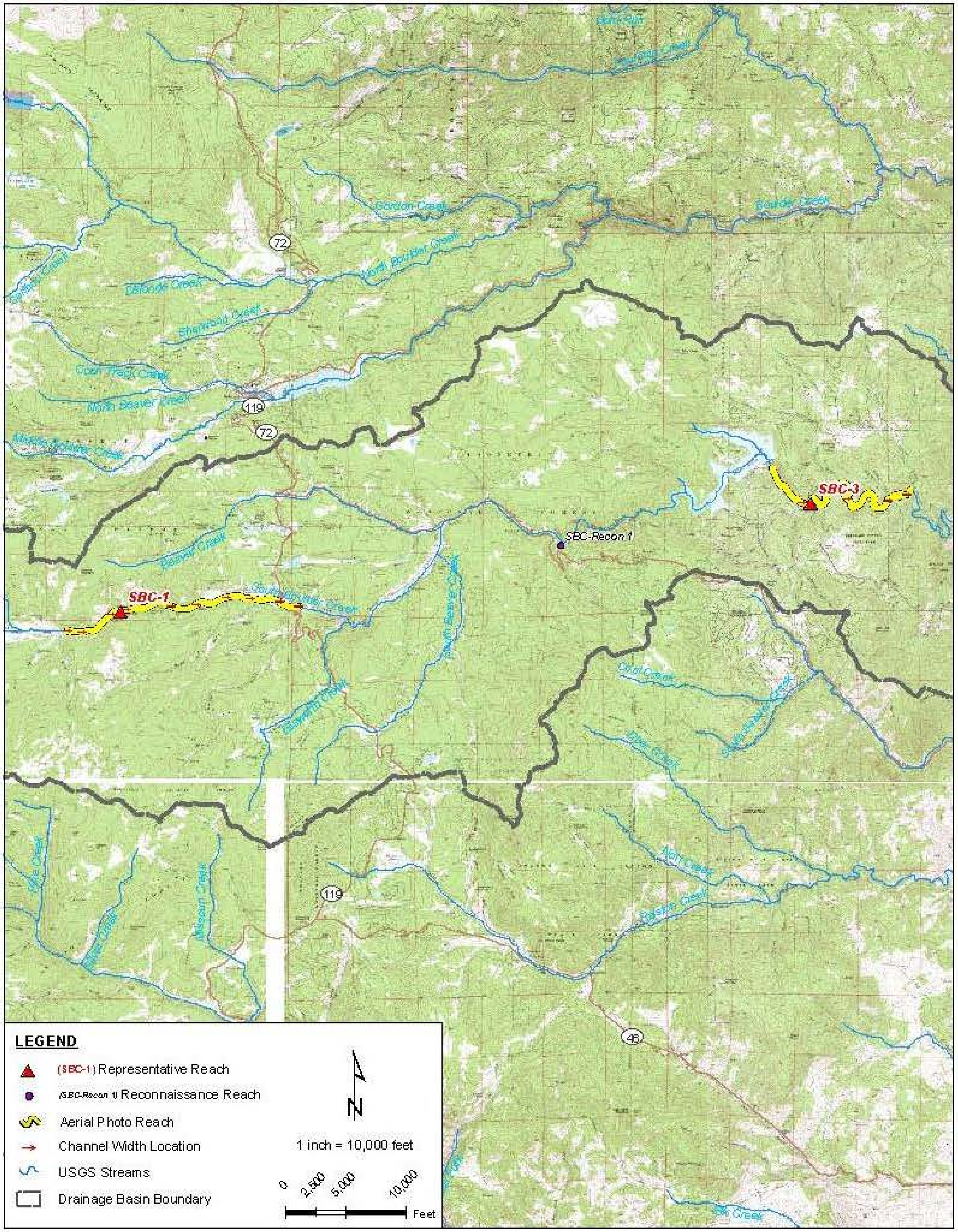


Figure E-3.6: South Boulder Creek Watershed Map with Assessment Locations



Photographs of Representative Reaches, Existing Conditions:

FRASER RIVER SITES
FR1 – Fraser River above Winter Park Gage

FR1: Downstream end of reach, looking downstream. Note uniform flow, dense vegetation, and large cobbles throughout reach.

FR1: Middle of reach, looking downstream. Again note uniform flow, dense vegetation, and large cobbles throughout reach. Banks shown on right and left appear stable.

FR1: Upstream end of reach, looking upstream. Note large cobbles throughout reach, small amounts of woody debris, and bar on right.

FR1: Close-up view of bar and woody debris shown in photograph above. Note amount of sand on bar below tree root mass.

FR1: View of cross section in reach with large amounts of sand stored on bed. Note gently sloping to overhanging bank in background. Bank appears stable.

FR1: Close-up view of streambed shown in photograph above. Note large amounts of sand stored on bed.

FR1: View of cobble bar and side channel, looking upstream.

FR1: Close-up view of side channel shown in photograph above, looking upstream. Note sand deposit in center, and dense vegetation.

FR1: View of bank with dense herbaceous vegetation. Note stable appearance of bank.

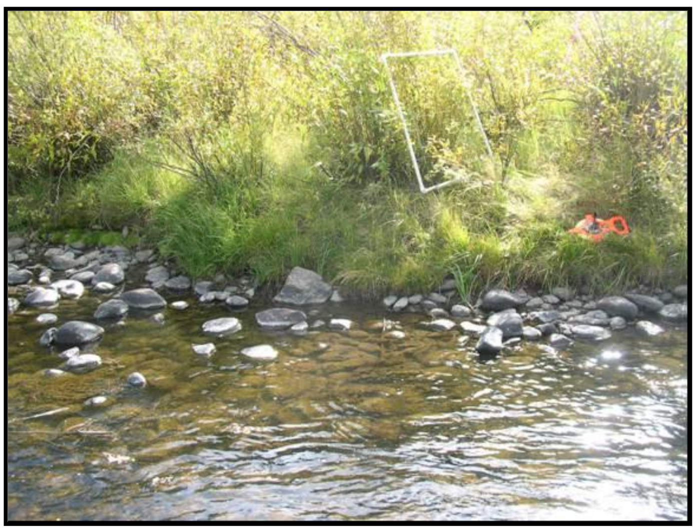
FR1: View of stable bank and adjacent riparian area. Note herbaceous and woody vegetation.

FR1: View of slightly overhanging bank with herbaceous and woody vegetation. Bank appears stable with limited sands and fines.

FR2 – Fraser River below Tabernash

FR2: View of reach and valley, looking upstream. Note dense herbaceous vegetation on low, stable, vertical banks, and cobble bars in distance on right.

FR2: View of channel and bank in reach and valley. Note dense herbaceous and woody vegetation on low vertical banks. Banks appear stable.



FR2: View of channel and bank in reach. Note dense vegetation and organic matter on cobbles underwater in foreground.

FR2: View of grasses along bank with gravelometer. Note organic material deposited around cobbles on left.

FR2: Close-up view of bank with mosses, grasses, and cobbles.

FR3 – St. Louis Creek below West St. Louis Creek

FR3: View of reach looking upstream. Note riffle and glide type flow, and cobble bar in distance on left.

FR3: Close-up view of cobble bar shown in photograph above, looking upstream. Note herbaceous and woody vegetation, and that banks appear stable with limited sands and fines.

FR3: View of reach looking upstream. Note small amount of woody debris in channel, riffle and glide-type flow, and cobble bar on right.

FR3: View of cobble bar and bend in reach, looking upstream. Note stable bank in background on right.

FR3: View of cobbles in channel and on bar. Note dense vegetation along gently sloping banks, and that banks appear stable.

FR3: View of bank vegetation. Note large amounts of organic matter on stream bed cobbles.

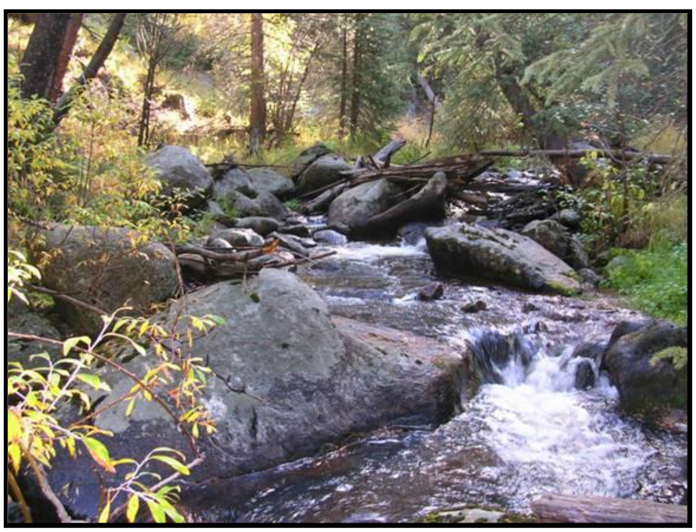
FR3: View of coarse sand to medium-sized gravel deposited on point bar along stream bank.

FR3: Looking downstream at backwater caused by beaver dam at downstream end of reach. Water depth ranges between 2 and 3 feet deep.

FR4 – Ranch Creek below South Fork

FR4: View of reach looking downstream. Note large boulders in channel and dense vegetation along stable banks.

FR4: Looking downstream at view of reach further downstream. Note uniformity in flow and straight channel.



FR4: View looking upstream at large boulders in channel and step-pool configuration.

FR4: View of large boulders, mosses and woody debris along bank. Note that bank appears stable.

FR4: Example of sand deposit downstream of boulders along bank.

FR5 – Fraser River below Denver Water's Diversion

FR5: View of reach looking downstream. Note riffle and glide type flow and sand deposits at downstream end of point bar.

FR5: View of reach looking downstream. Note stable overhanging banks vegetated with thick grasses and willows.

FR5: View of reach looking downstream. Note significant amount of woody debris in channel. Slower water flow is visible in foreground and riffle flow is visible in the distance.

FR5: View of point bar and bend in reach, looking upstream. Note sand deposition at downstream end of point bar.

FR5: View of sand deposits above bankfull elevation.

FR5: View of beaver dam located immediately upstream of reach.

FR5: View of overhanging bank stabilized by thick grasses and roots of woody vegetation. Note larger substrate with limited sands and fines in the foreground.

FR5: Looking downstream at vertical banks in the vicinity of Midland Campground. Note banks stabilized by roots of woody vegetation with limited sands and fines.

FR6 – Jim Creek below Denver Water's Diversion

FR6: View of reach looking upstream. Note large cobble in streambed with limited sands and fines. No flows in the stream at the time of the assessment.

FR6: Looking upstream at dry portion of channel. Note willows that appear to be growing below bankfull elevation and potentially encroaching on the historic active channel.

FR6: Upstream end of reach, looking downstream. Note heavy cover over channel and boulders in bank.

FR6: Close-up view of cobble in channel bed. Observed substrate was generally large with only limited pockets of sands and fines.

FR6: View of sand and gravel deposited behind woody debris. This sized material was generally located in areas where slack water likely occurs in times of flow events.

FR6: Close-up view of gravel deposits in channel cobble near bank with limited sands and fines.

FR6: View of channel in an area with thick vegetation and woody debris.

FR6: View of woody debris in channel. Note sand deposited behind debris at lower right. Debris appeared to have been transported during past higher flow event.

FR6: View of channel facing upstream. Note stable banks on right.

FR7 – Vasquez Creek above Denver Water's Diversion

FR7: View of reach looking upstream. Note riffle type flow in foreground, bend pool in the distance, and well vegetated, stable banks.

FR7: View of reach looking upstream. Note shallow riffle flow and cobble material deposited downstream of woody debris.

FR7: View of sandy deposits along bank.

FR7: View of sand deposited in channel below undercut, but stable bank.

FR7: View of woody debris in channel, looking upstream. Note boulder-sized material along undercut bank.

FR7: View of point bar, looking downstream. Bar is composed primarily of cobble-sized material. Note sandy deposit at downstream end of point bar.

FR7: View of densely vegetated stable banks, looking upstream.

FR7: View of willow-lined, stable, undercut bank. Note dense stands of spruce trees in distance on east bank.

WILLIAMS FORK RIVER SITES

WF1 – Williams Fork near Sugarloaf Campground

WF1: View of reach looking upstream. Note point bars on inside of bends and woody debris across channel. Woody and herbaceous vegetation is visible along banks. Areas of riffle and glide type flow pictured.

WF1: Close-up view of point bar, looking downstream. Note large amounts of sand in bar.

WF1: Looking downstream at exposed cobbles in channel and minor braiding. Banks are slightly overhanging and stable. Note the woody debris along the left bank.

WF1: Close-up view of point bar. Note large amounts of sand on right side of bar and woody debris along the left bank. Regions of riffle and glide type flow pictured.

WF1: View looking upstream at woody debris in channel and cobbles on point bar. Riffle type flow pictured.

WF1: View looking upstream at bend with glide type flow and cobble point bar. Note overhanging areas of bank.

WF1: Looking downstream at woody debris and exposed cobbles in channel. Note point bar on inside of bend at left, and vegetated stable bank on right.

WF1: View of bend with riffle type flow and cobble bar, looking upstream. Note overhanging areas and woody debris along the right bank.

WF2 – Williams Fork below Steelman Creek

WF2: View of channel and bank in reach. Note large boulders, vertical to overhanging banks, and sand deposit on bar.

WF2: View of bank in reach. Note large cobbles and dense vegetation along bank, and that banks appear stable.

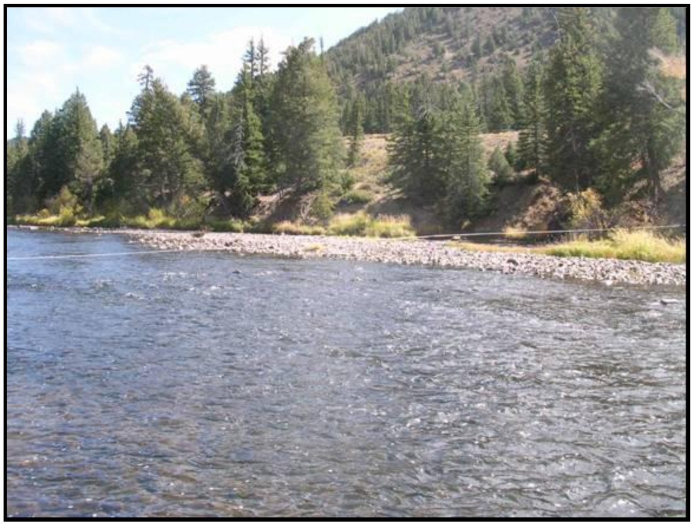
WF2: View of bank in reach. Note gently sloping stable bank with dense herbaceous vegetation. Also note large cobbles along bank.

WF2: View of vertical to overhanging bank in reach. Note large cobbles and boulders along bank and in channel.

WF2: View of large boulders comprising bank and in channel. Note overhanging banks.

WF2: View of vertical section of bank. Bank appears to be instable.

COLORADO RIVER SITES
CR1 – Colorado River above Parshall



CR1: View of reach and exposed cobble bar, looking upstream.

CR1: View of reach looking downstream. Note small riffles and glide type flow.

CR1: View of reach looking upstream. Note dense vegetation along gently sloping stable banks, and organic material at edge of water on left.

CR1: View of reach looking downstream. Note low vertical stable bank with dense herbaceous vegetation.

CR1: View of cross-section in reach. Note herbaceous and woody vegetation.

CR1: Close-up view of low bank with herbaceous vegetation. Note organic material deposited along bank.

CR1: Close-up view of stream bed substrate. Note organic material on cobbles.

CR1: Close-up view of stream bed substrate. Note aquatic plant material growing in cobbles.

CR2 – Colorado River at Kemp-Breeze State Wildlife Area

CR2: View of reach looking downstream. Note low sinuosity and stable banks with herbaceous and woody vegetation.

CR2: View of reach looking upstream. Note varied riffle and glide type flows, with relatively shallow flow depths. Also note stable vegetated banks along both sides of the river.

CR2: View of shallowly submerged point bar. Note cobble-sized material forming bar.

CR2: View of woody debris from fallen cottonwood branches along stable banks.

CR2: View of cottonwood trees and grasses along stable south bank.

CR2: View of willows and grasses along north bank.

CR2: View of island at upstream end of reach.

BLUE RIVER SITE

BR1 – Blue River below Confluence with Boulder Creek

BR1: View of reach looking downstream. Channel substrate consists of relatively large materials (cobbles and boulders) and significant amount of faster water. Banks are stable and vegetated with both woody and herbaceous vegetation.

BR1: Cobble bars were observed on inside bends. Banks include mixture of grasses, shrubs, and larger trees.

BR1: Channel cross-section and banks appeared to be stable. Larger cobble material observed along banks and in stream channel.

BR1: Substrate ranged from limited amounts of fines and sands all the way up to occasional large boulders. Fine deposits were located behind flow obstructions like the large boulder seen in the foreground of this photograph.

BR1: General view of reach showing channel meander with cobble bar in the foreground. Sand and fines exist but make up a small portion of bar material. Banks are stable and well vegetated.

BR1: General view of reach. Flows here are predominately shallow riffles with larger (boulder) sized materials in the channel. Bed and banks appear stable with no signs of aggradation.

NORTH FORK SOUTH PLATTE RIVER SITES

NF1 –- North Fork South Platte River near Shawnee

NF1: View looking upstream at riffle type flow and small vertical bank. Note the woody debris along the bank.

NF1: View looking downstream at exposed cobbles on downstream side of debris jam (jam not visible in this photograph – see photograph below).

NF1: View of debris jam and exposed cobbles on downstream side of debris jam. Photograph is taken looking upstream. Note high water mark on boulder in left foreground, and overhanging bank in background.

NF1: View of cobble bar above bedrock bank control, looking upstream. Note rapid riffle type flow.

NF1: View of cobble bar above bedrock bank control and bend, looking downstream. Note rapid riffle type flow and overhanging bank and woody debris in right foreground.

NF1: View of bedrock bank control at bend.

NF1: Upstream end of reach, looking downstream at cobble bar and bed rock controlled bend. Note bank protection in right foreground.

NF1: Close-up view of downstream end of bank protection as noted in the photograph above. Note that the banks are near vertical and appear potentially instable.

NF1: View of upstream end of bank protection. Note cobble bar in foreground.

NF1: View of left bank at upstream extent of reach. Note overhanging tree roots indicating potential bank instability.

NF1: View of exposed vertical bank above reach, looking upstream. Bank is approximately 10 feet tall and appears potentially instable.

NF2 – North Fork South Platte River near Pine

NF2: Looking upstream at bend in reach. Note small riffles and glide type flow. Herbaceous and woody vegetation is present along banks. Note bank on left is overhanging.

NF2: View of small riffles and glide type flow, looking upstream. Note burned hillside in background.

NF2: View of bank looking downstream. Note rock stabilization and sandy slopes.

NF2: Looking downstream at bank stabilization Area 1.

NF2: View of bank stabilization Area 1 and bend, looking downstream. Note small riffles and glide type flow, and bank stabilization Area 2 in distance.

NF2: View of bank stabilization Area 2, looking upstream. Note reinforced bank appears stable.

NF2: View of overhanging bank. Bank appears potentially instable.

NF2: View looking upstream at glide type flow with concrete wall and diversion turnout.

SOUTH BOULDER CREEK SITES

SBC1 – South Boulder Creek above Gross Reservoir

SBC1: View of reach looking upstream. Note fast riffle type flow and tall banks that appear stable.

SBC1: View of reach looking upstream. Note large cobbles along edge of water and tall bank in background.

SBC1: View of reach looking downstream. Note fast riffle type flow, and large bank material. Note banks are steep but appear stable.

SBC1: View of exposed bank area.

SBC1: View of localized bank instability Area 1. Note large cobbles along the water's edge.

SBC1: View of material in bank instability Area 1 as identified in the photograph above.

SBC1: View of localized bank instability Area 2. Note large cobbles along water's edge.

SBC3 – South Boulder Creek below Gross Reservoir

SBC3: Upstream end of reach looking upstream. Note bedrock outcrops and bank on left that appears stable.

SBC3: View of middle section of reach, looking downstream. Note large cobbles in channel.

SBC3: View of channel and left bank. Note steep bank with exposed sandy soil. Bank appears to be potentially instable in this area.

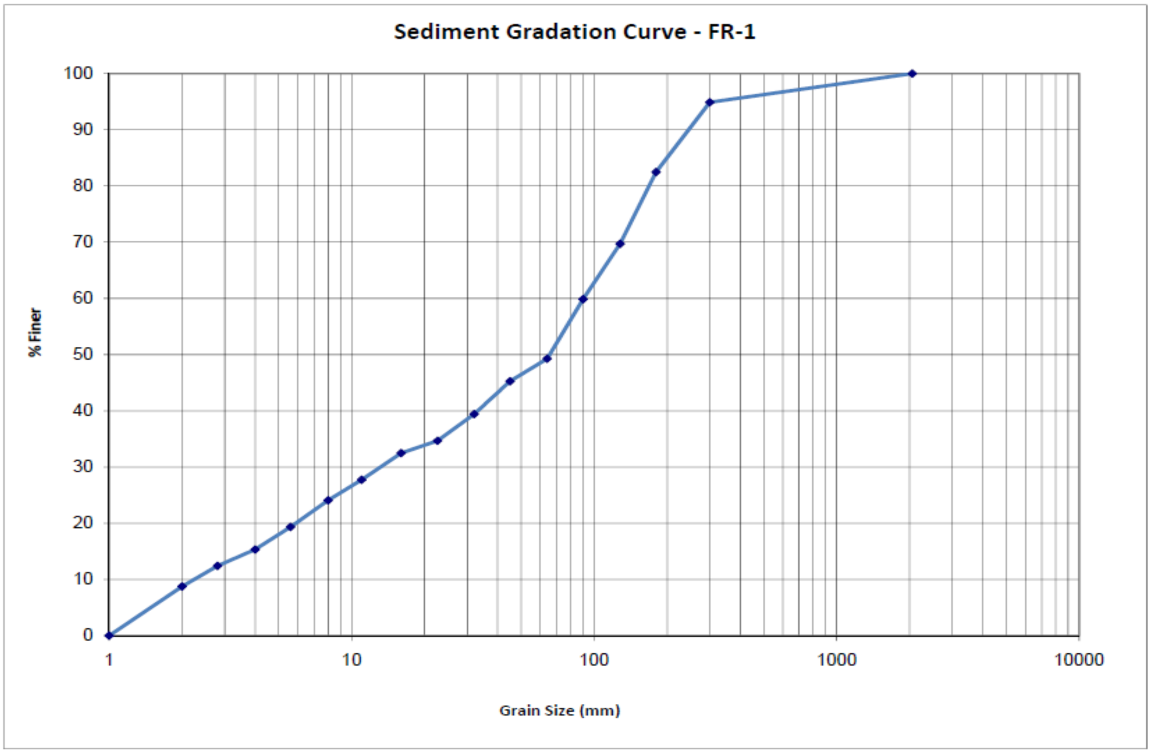
SBC3: View of right bank. Bank appears stable. Note sand stored on downstream side of boulder and cobbles. Note high water mark on boulder.

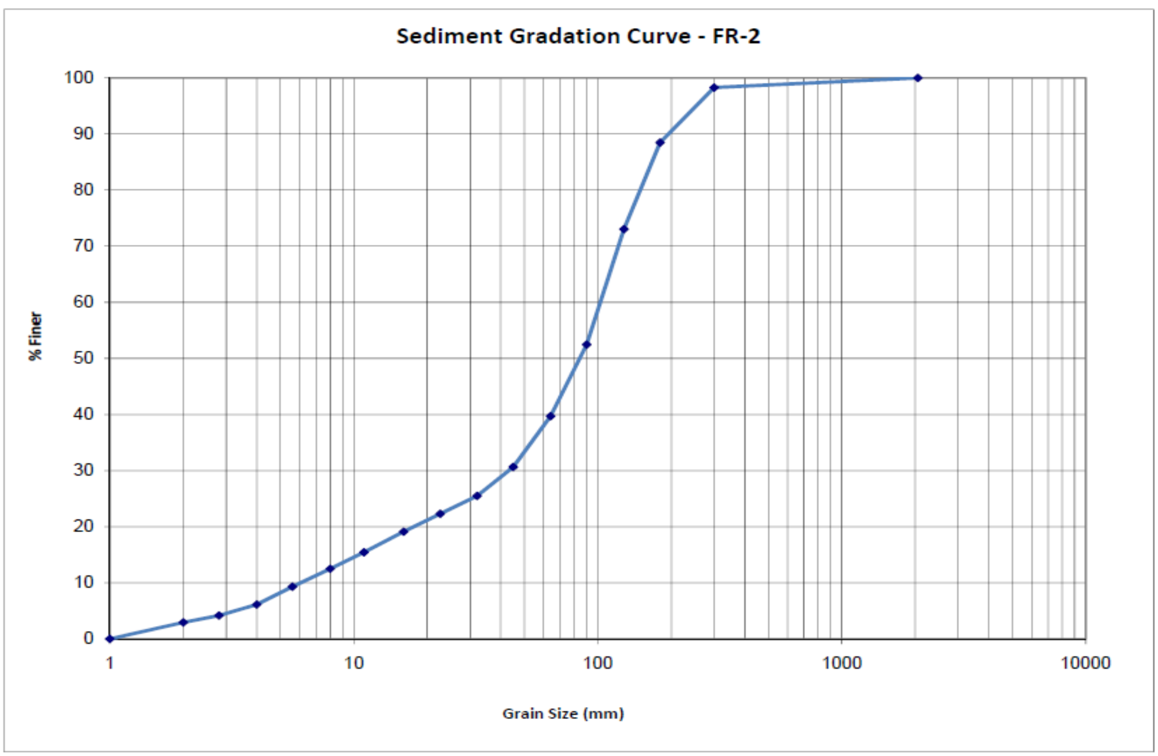
SBC3: View of right bank. Note stable appearance, gradual slope and riparian vegetation. Note high water mark on boulder.

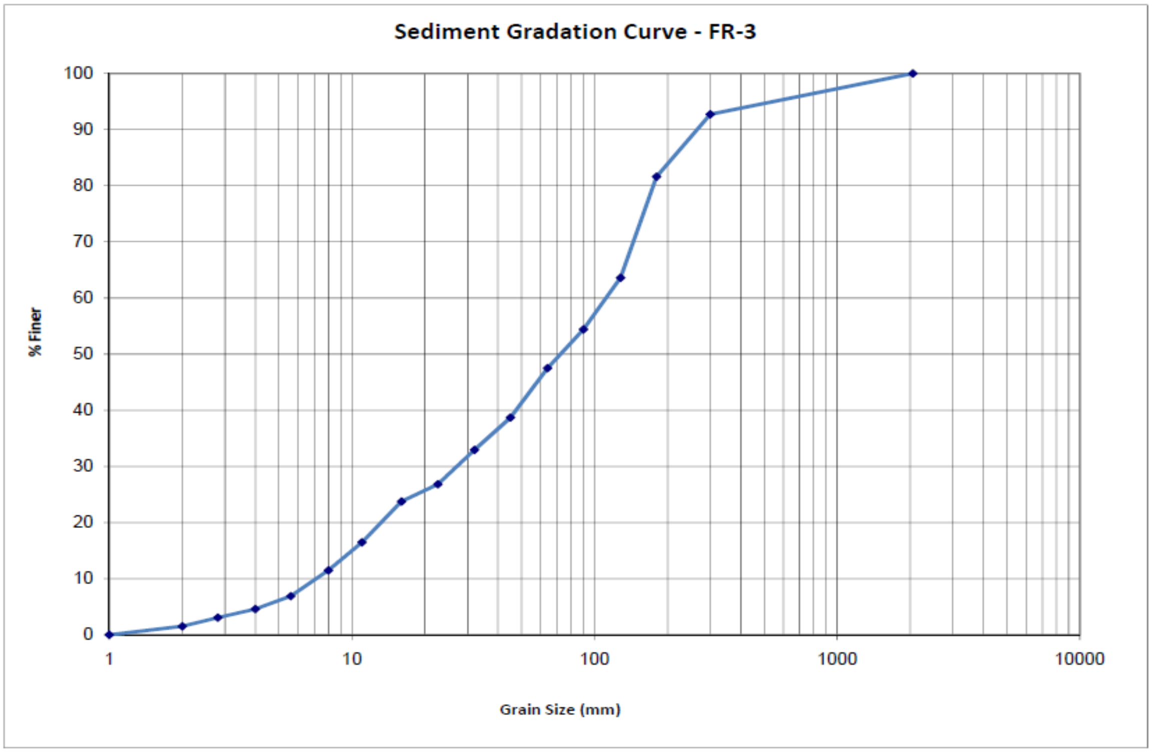
SBC3: View of high water mark on boulder. Note boulders, large cobbles, and woody debris in background on right.

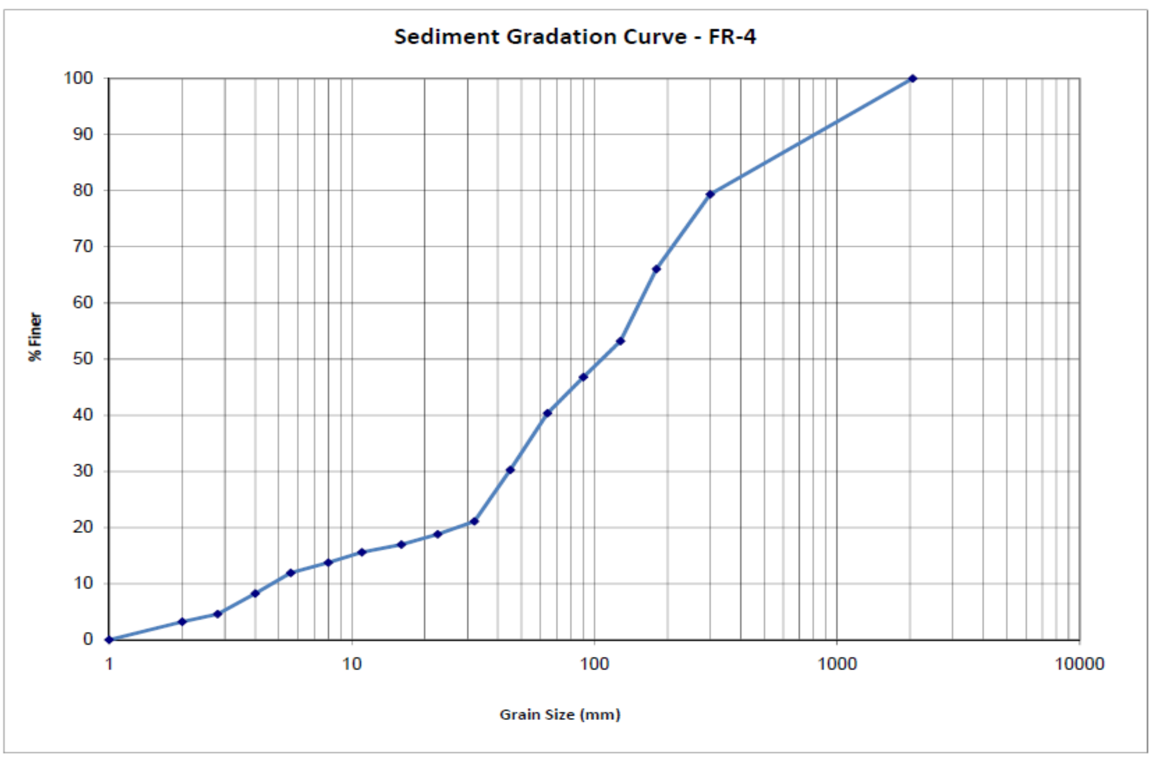
Sediment Gradation Curves for Representative Reaches

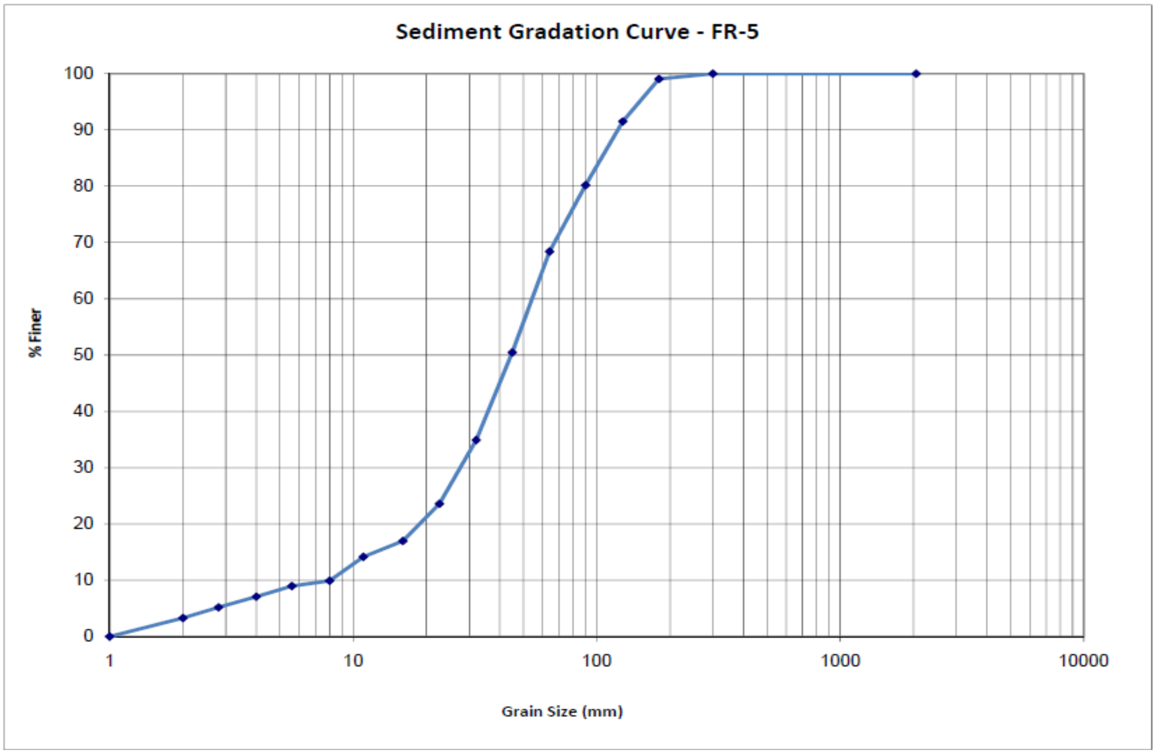
FRASER RIVER SITES

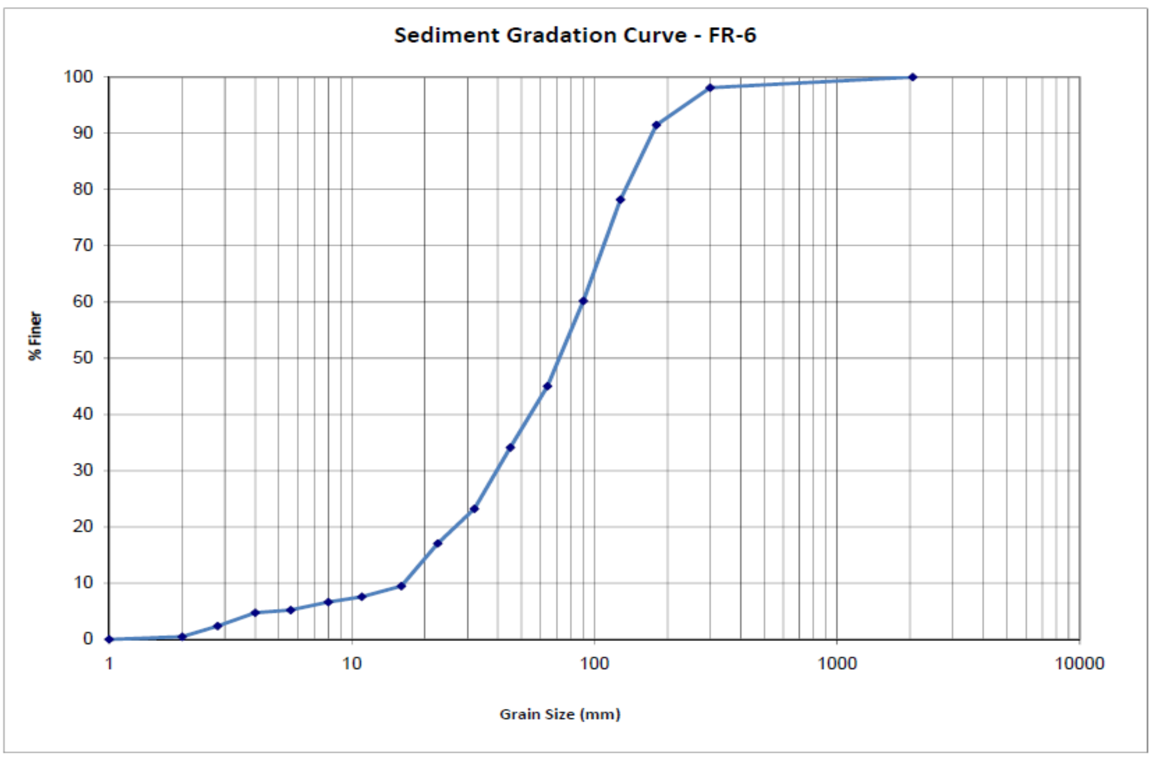





Sediment Gradation Curve - FR-3
100
90
80
70
60
50
40
30
20
10
0
% Finer
1
10
100
1000
10000
Grain Size (mm)


Sediment Gradation Curve - FR-4
100
90
80
70
60
50
40
30
20
10
0
% Finer
1
10
100
1000
10000
Grain Size (mm)


Sediment Gradation Curve - FR-5
% Finer
Grain Size (mm)
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000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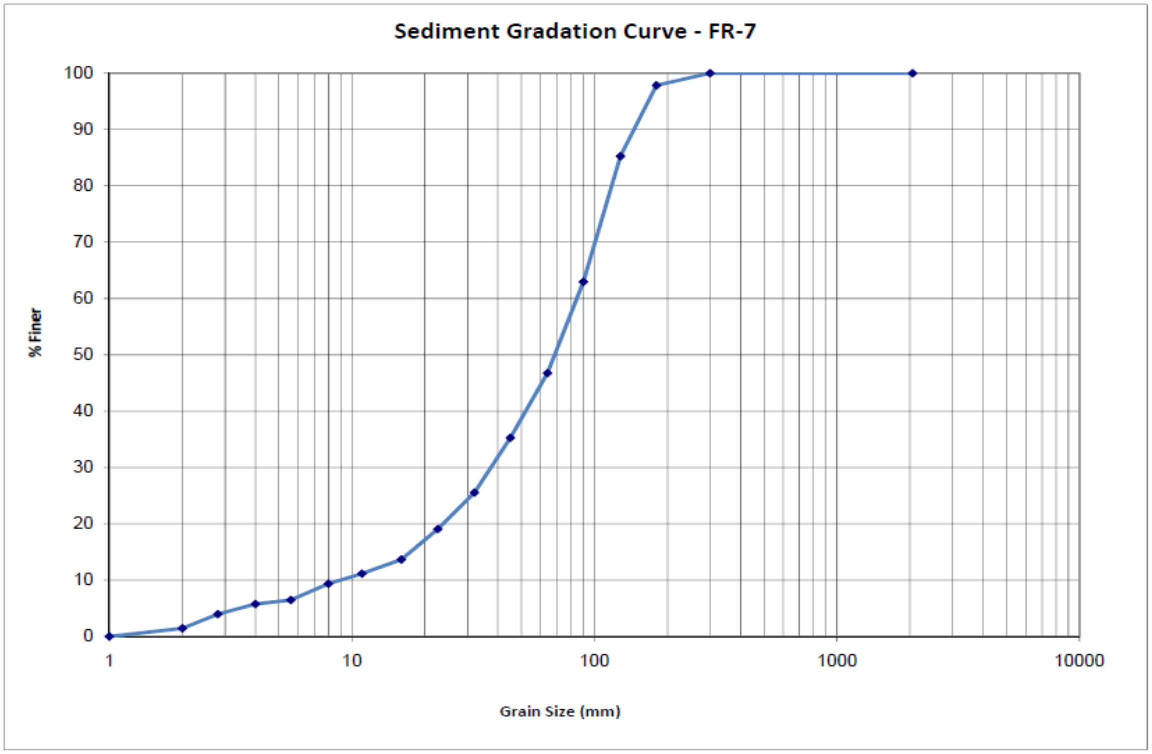
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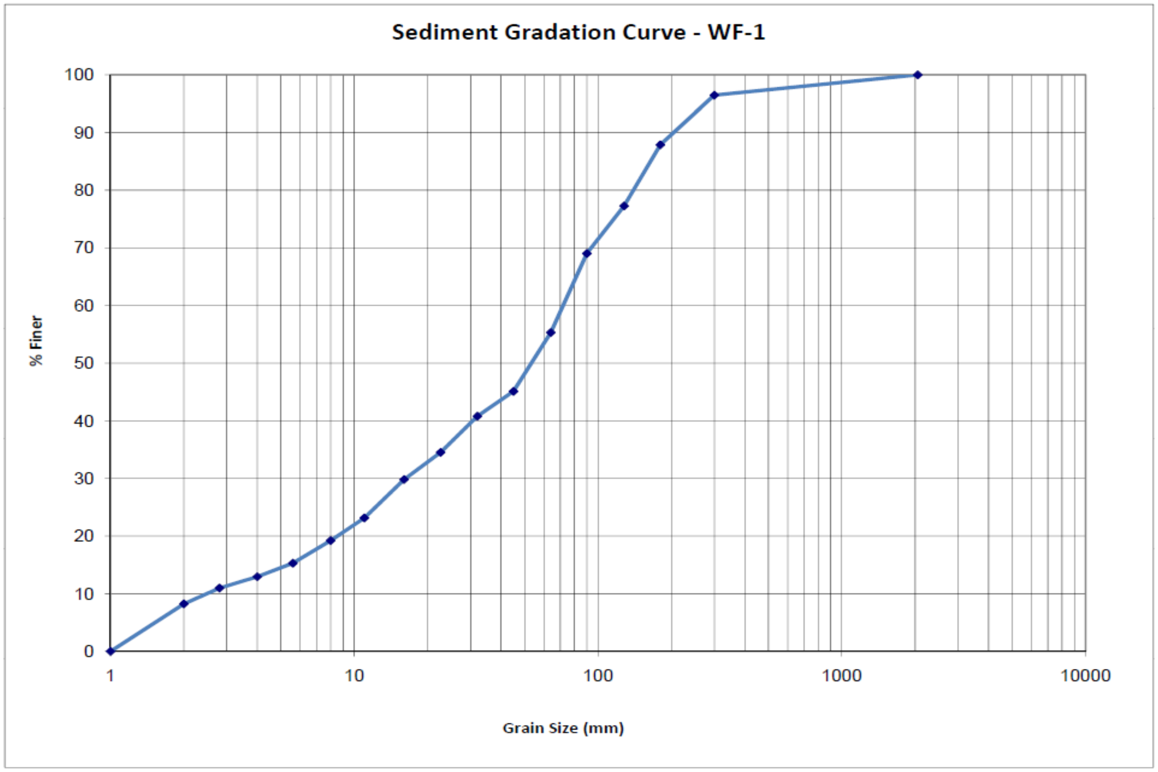
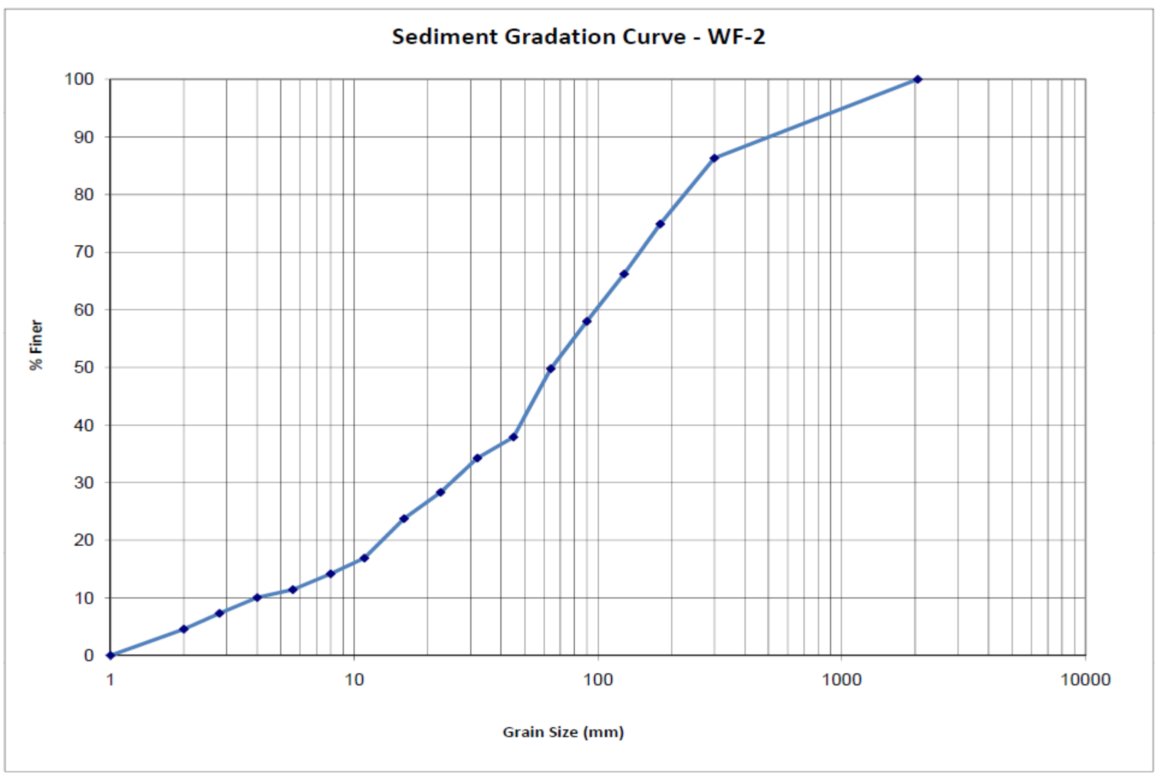
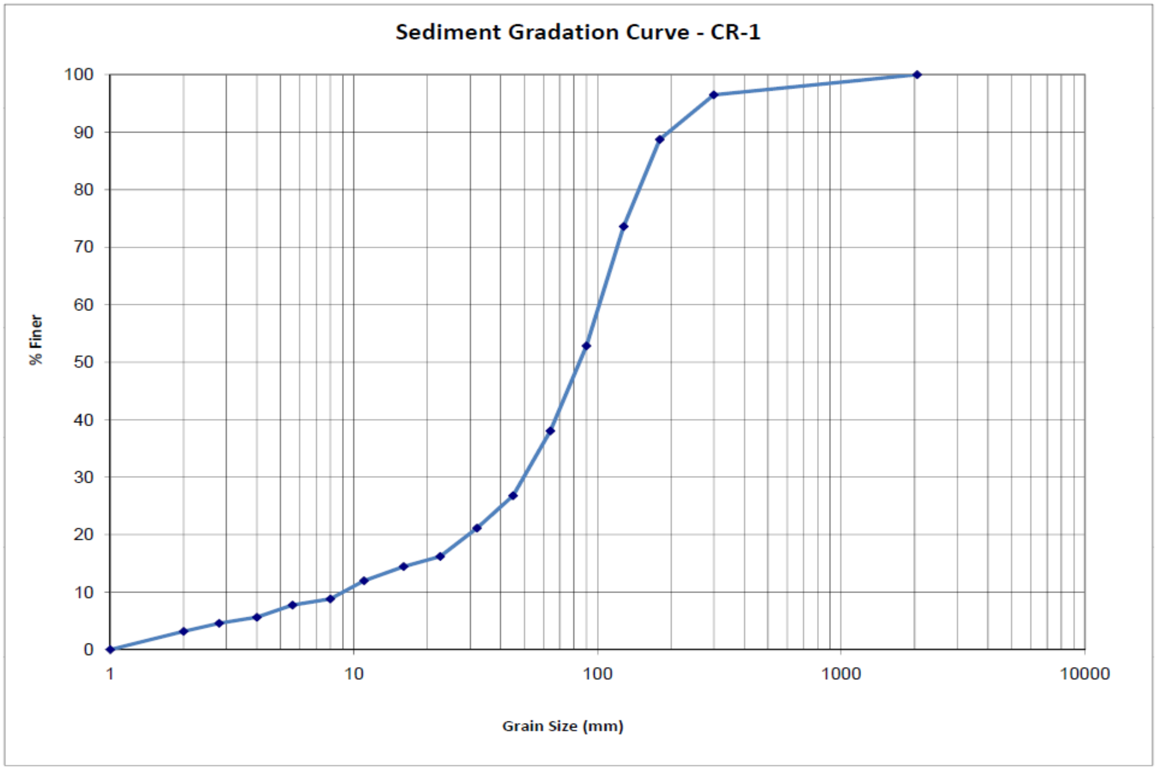
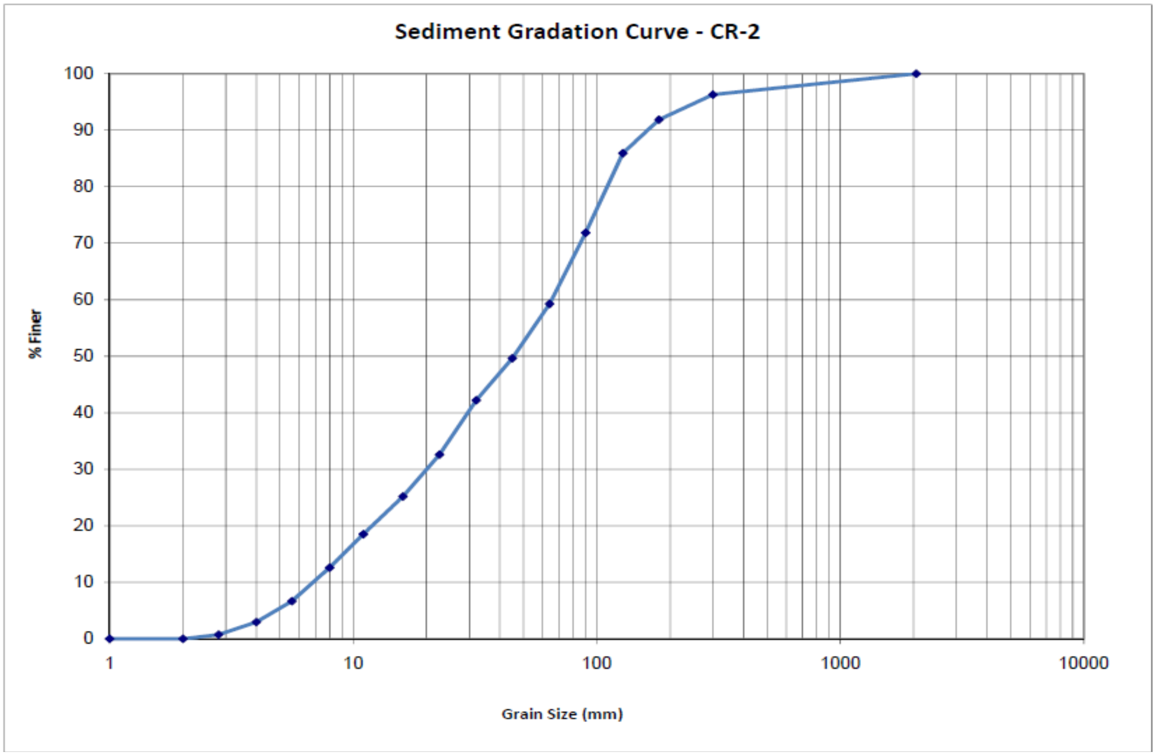


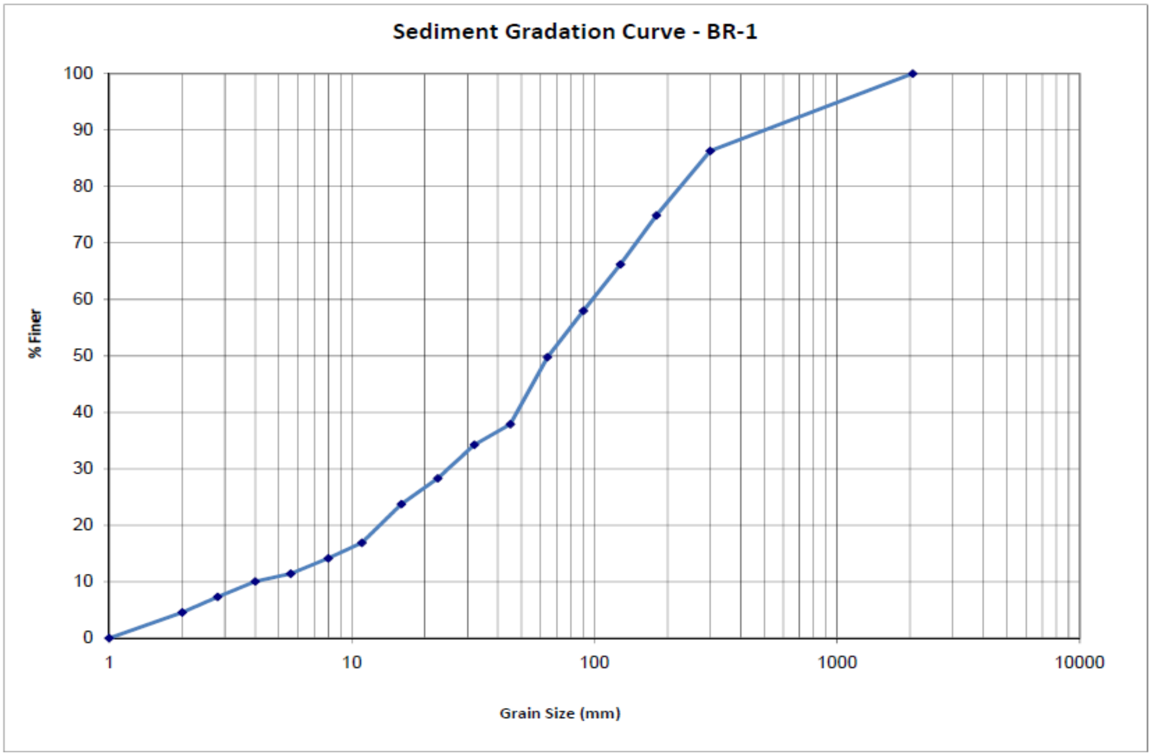


COLORADO RIVER SITES





BLUE RIVER SITE



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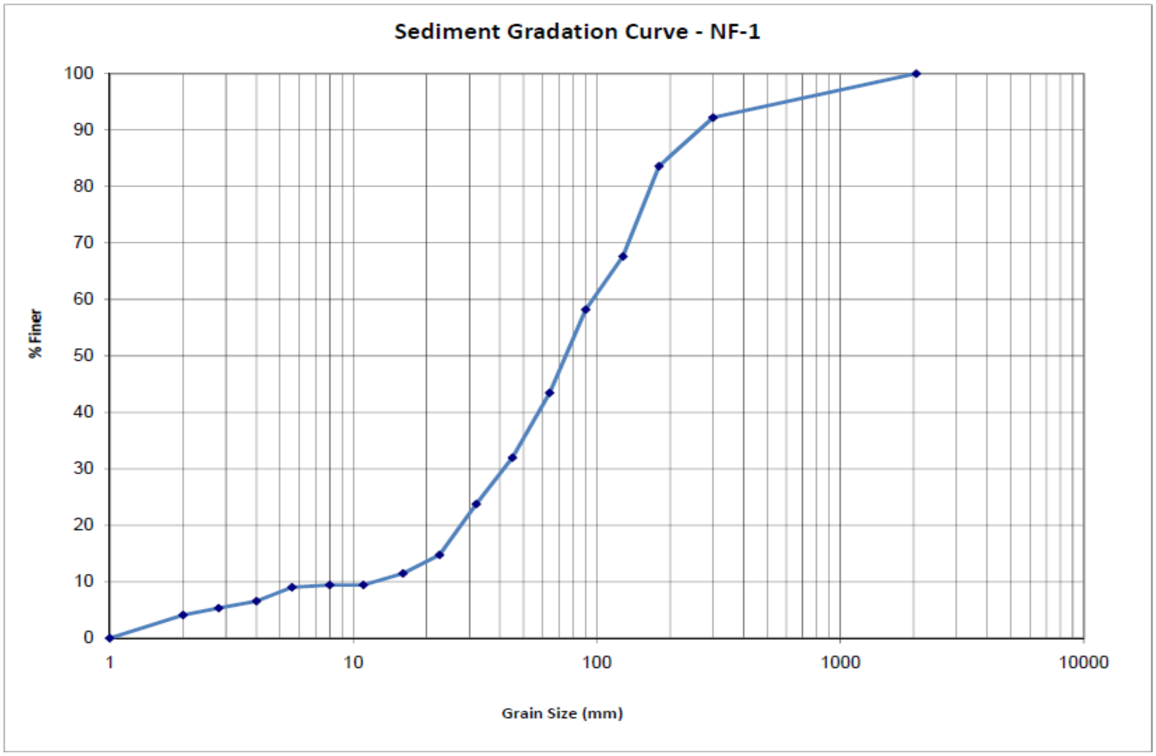
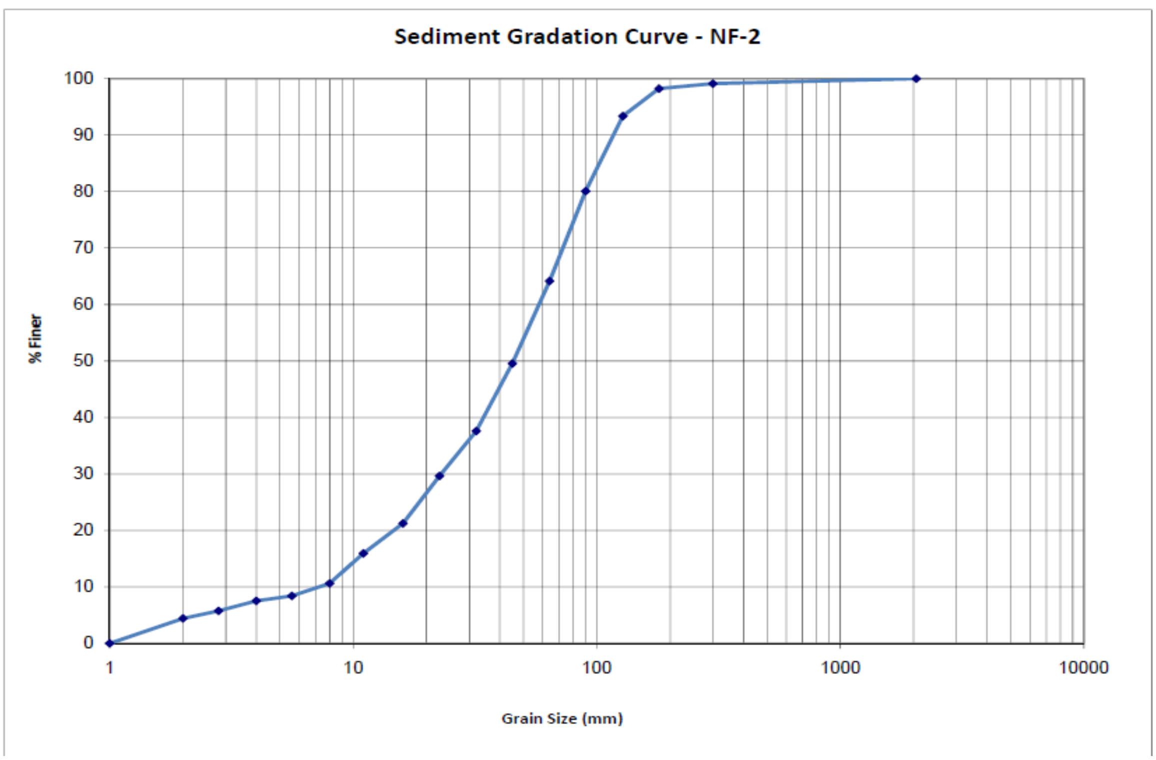
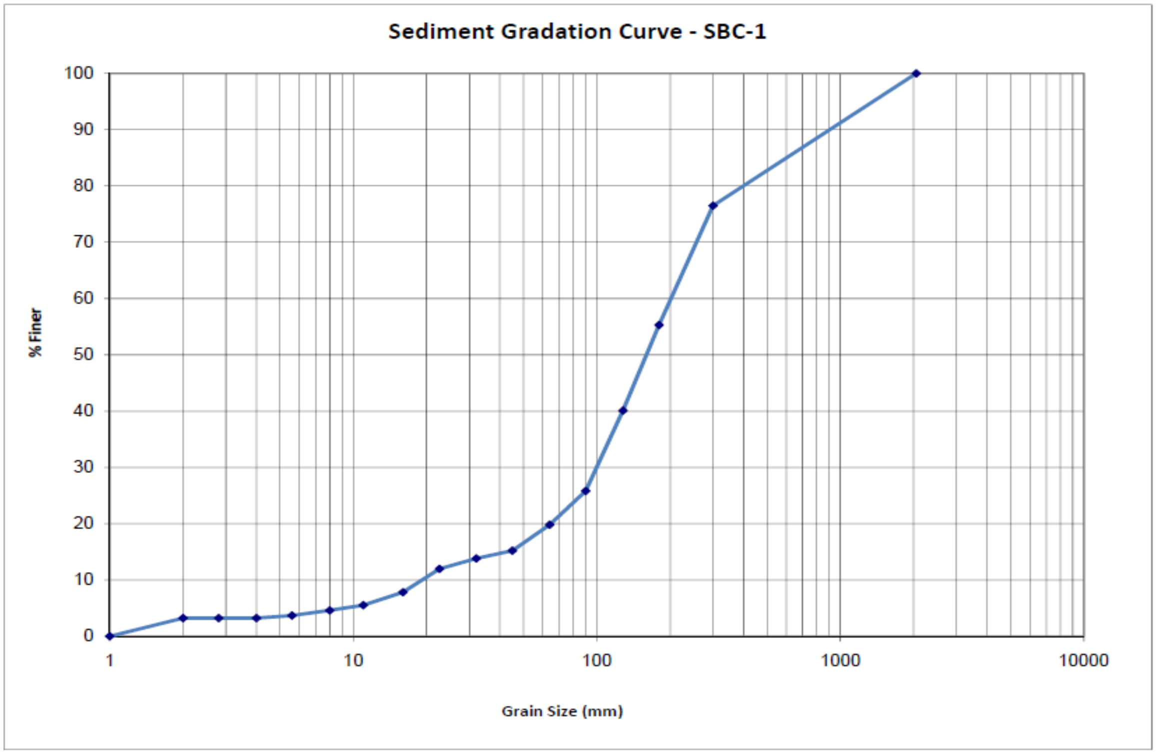
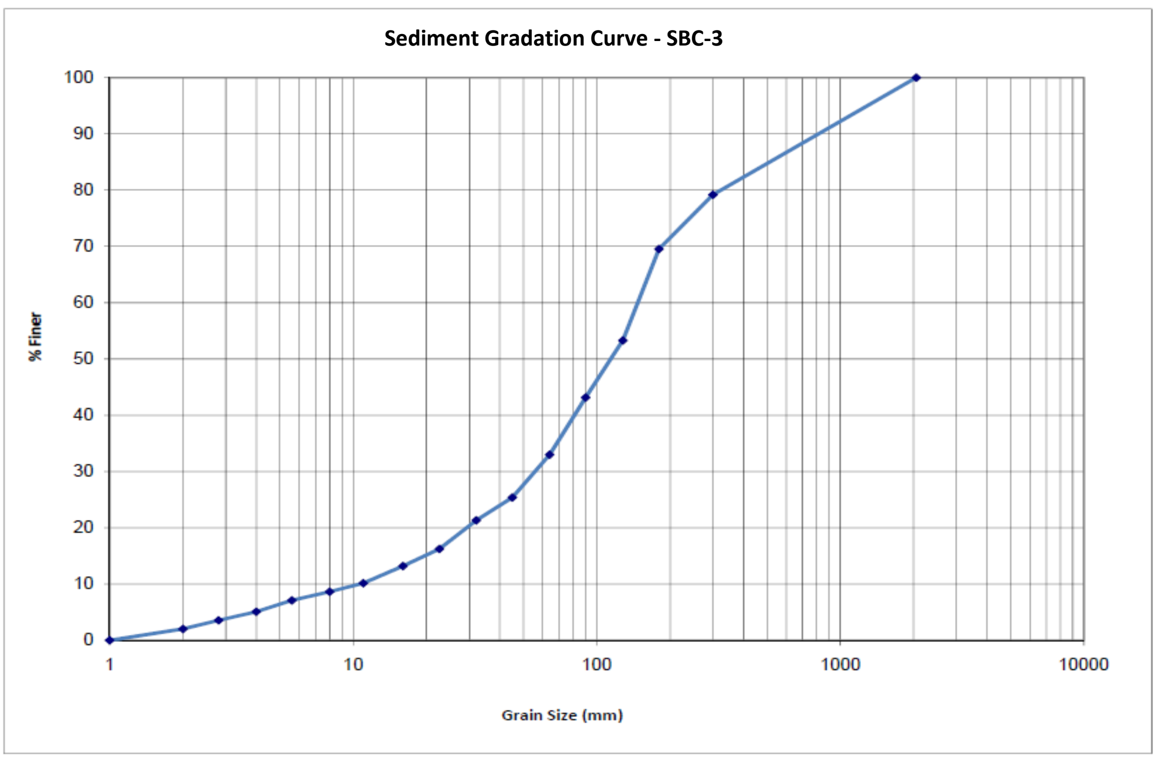




SOUTH BOULDER CREEK SITES





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Photographs of Additional Sites

NO BYPASS FLOW LOCATIONS
Fool Creek

Fool Creek: View looking downstream immediately below diversion. No flow exists in the channel and vegetation appears to have encroached on the channel.

Fool Creek: Minimal flows were observed further downstream. Debris and vegetation were noted in the channel.

Fool Creek: View upstream towards the diversion. Larger woody material covers the channel suggesting that higher flows had not passed the diversion in several years.

East St. Louis Creek

East St. Louis Creek: View of channel upstream of the diversion. Channel appears in natural form with stable, vegetated banks and natural cobble substrate. Some sand was observed near the diversion.

East St. Louis Creek: View below diversion facing downstream. No flow was occurring. Vegetation was noted establishing within the cobbles, suggesting vegetation encroachment into the historic active channel.

FRASER RIVER UPSTREAM OF DENVER WATER'S DIVERSION

Fraser River: Natural bars were observed on inside bends. Sand was observed to be stored along bars, behind flow obstructions and in the overbank areas.

Fraser River: Larger gravel and cobbles were observed in sections of the stream with faster moving water and along edges of channel.

Fraser River: Flows included faster moving riffle areas and deeper pools. Sand, cobbles, and finer materials were observed to be stored in point bars. New vegetation on bars, including areas near the active channel, indicates bar material may not be mobilized every year. Bank appears stable.

SOUTH PLATTE RIVER DOWNSTREAM OF HAYMAN FIRE IMPACTS

South Platte River: Excessive sediment includes generally sand to finer gravel-sized material that eroded from the hillside. Material was most prevalent in areas where flow velocities are lowest, such as behind obstructions.

South Platte River: Sediment was observed to have dispersed along the channel. Material appears to be stable at lower flows and is likely transported downstream during higher flow periods. Banks in this area appear to be stable.

South Platte River: Sand and gravel deposits were observed within the channel, on bars, behind flow obstructions, and in the overbank areas.

Appendix E-4
Nutrient Model Results

Figures:

Figure E-4.1: Ranch Creek at Mouth – Modeled Results for Total Nitrogen

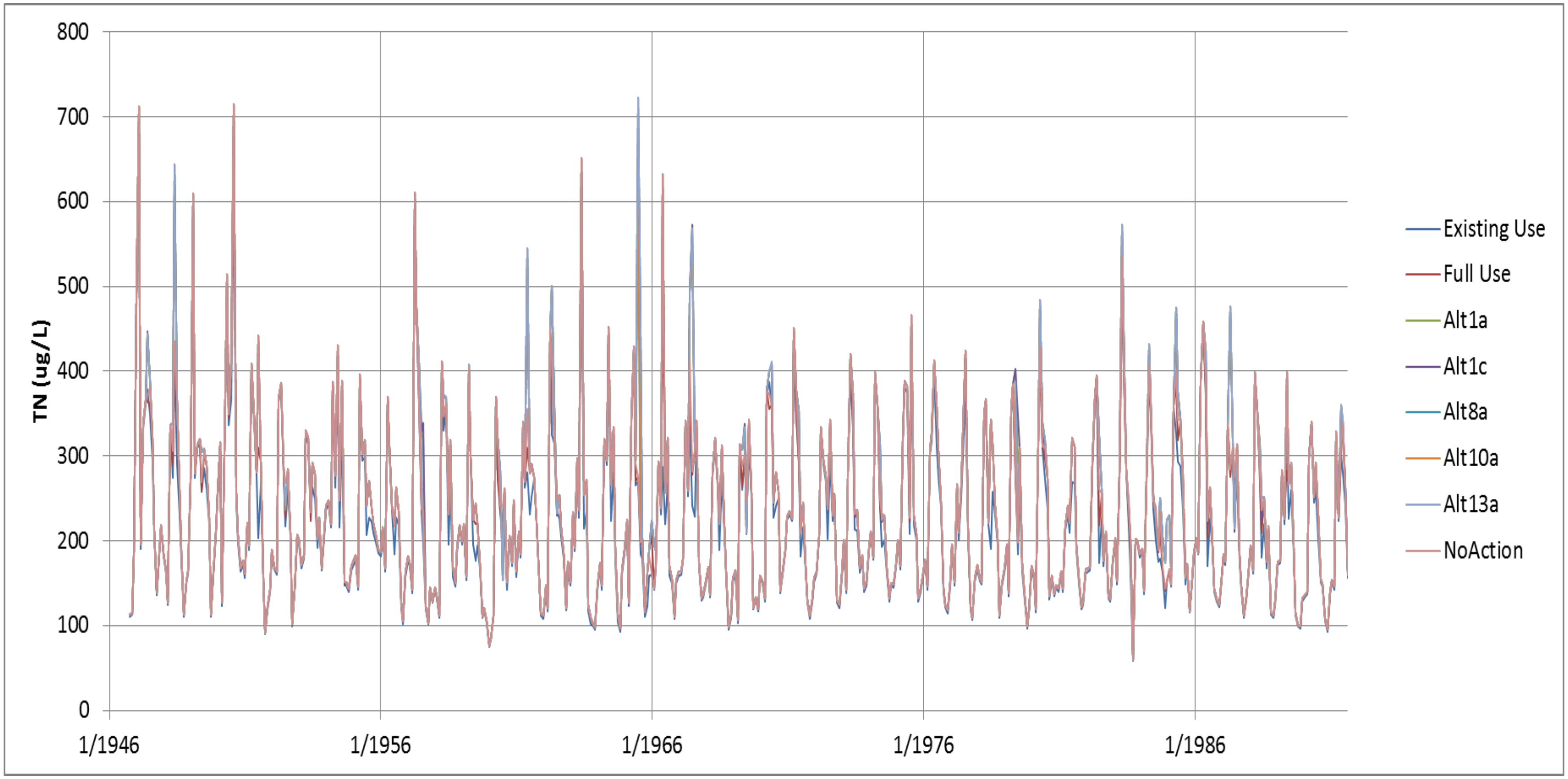


Figure E-4.2: Ranch Creek at Mouth – Modeled Results for Total Phosphorus

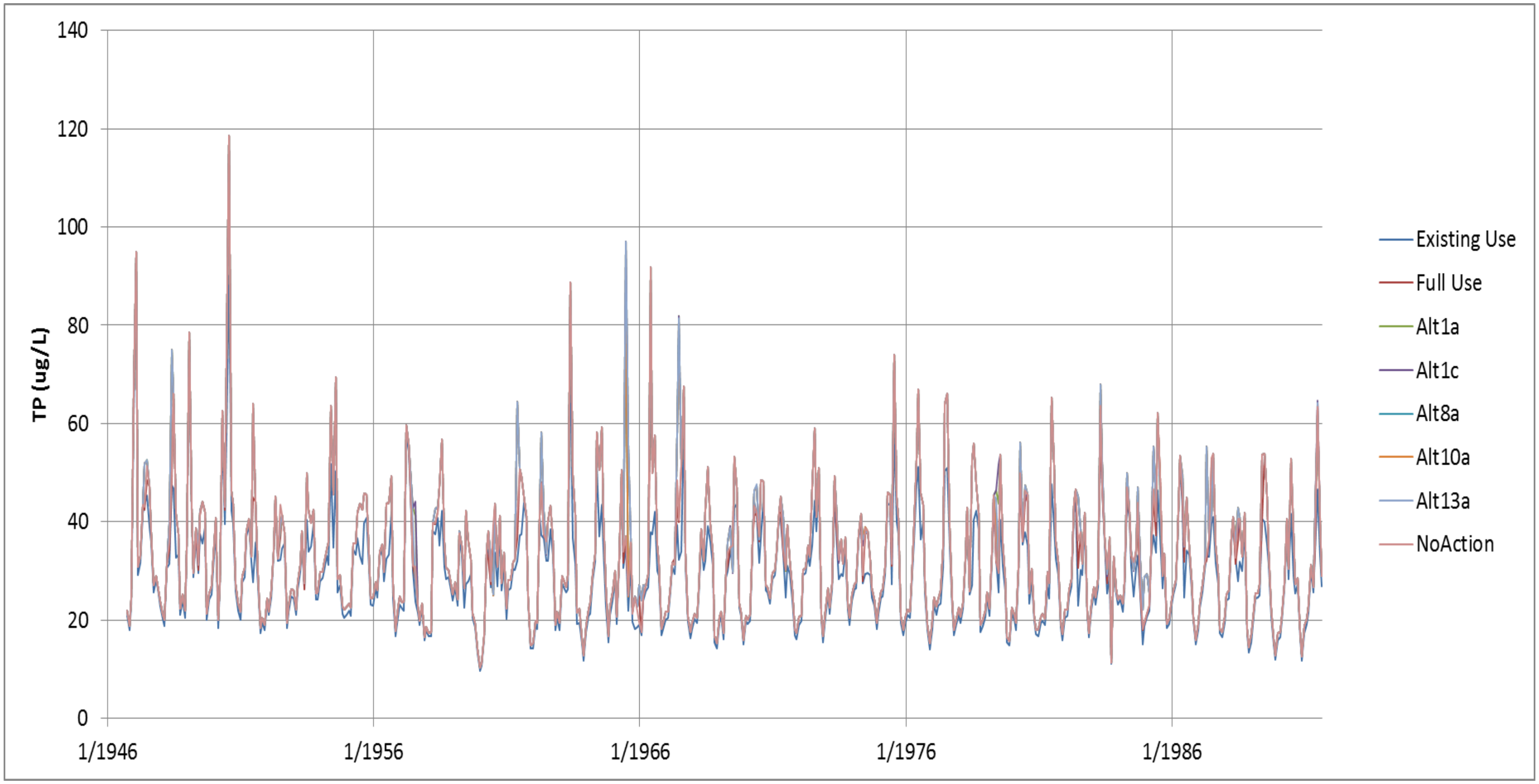


Figure E-4.3: Crooked Creek at Mouth – Modeled Results for Total Nitrogen

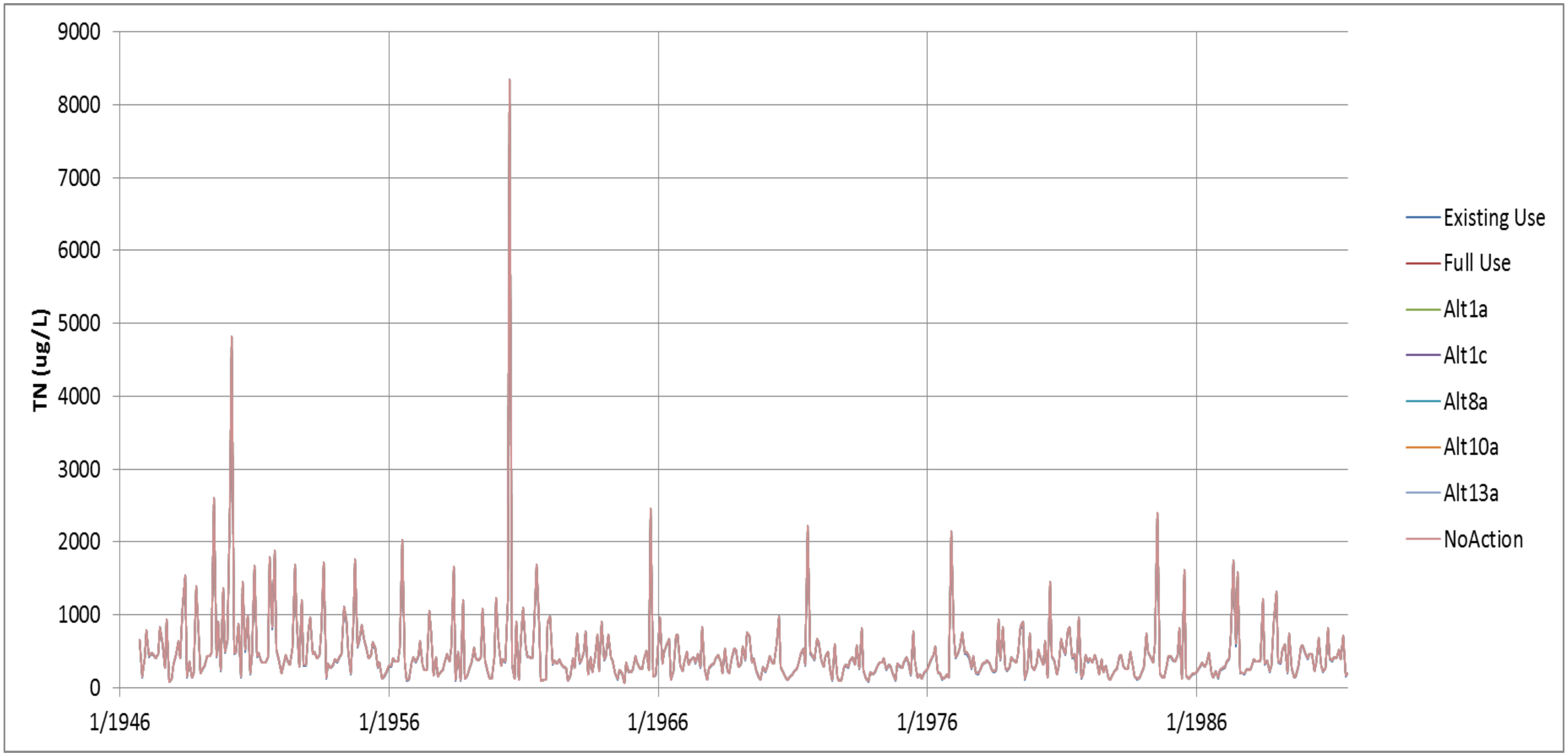


Figure E-4.4: Crooked Creek at Mouth – Modeled Results for Total Phosphorus

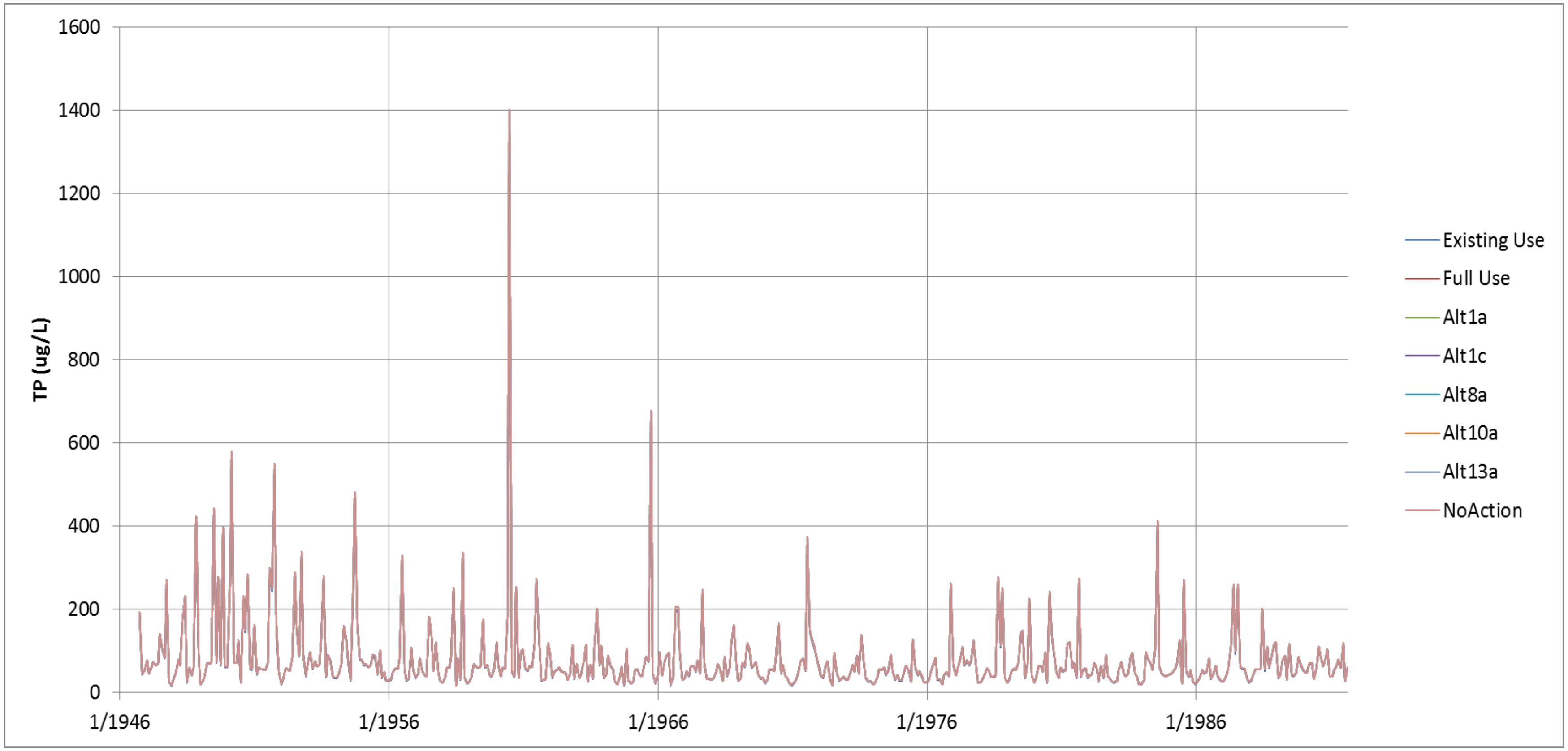


Figure E-4.5: Fraser River at Mouth – Modeled Results for Total Nitrogen

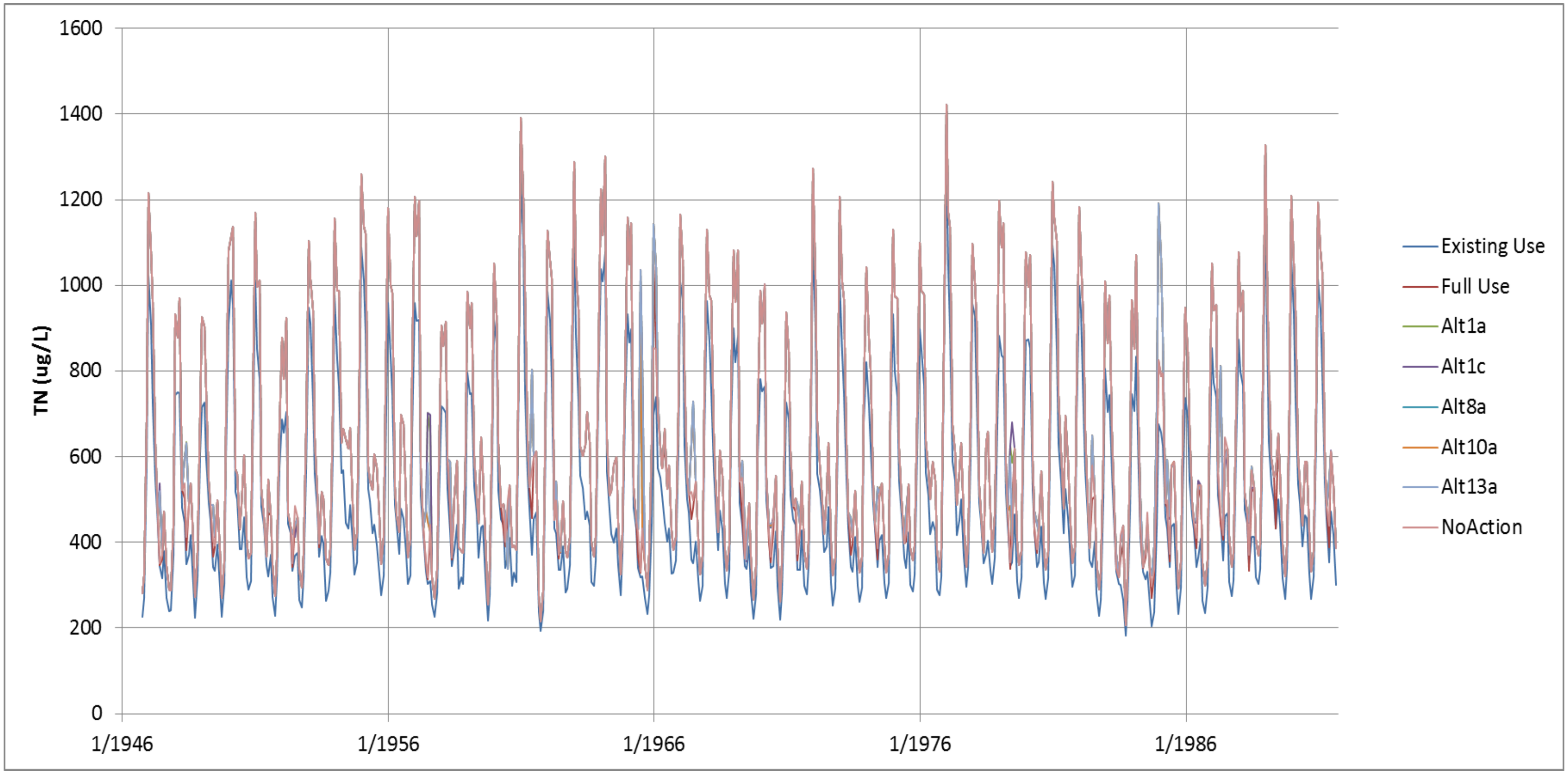


Figure E-4.6: Fraser River at Mouth – Modeled Results for Total Phosphorus

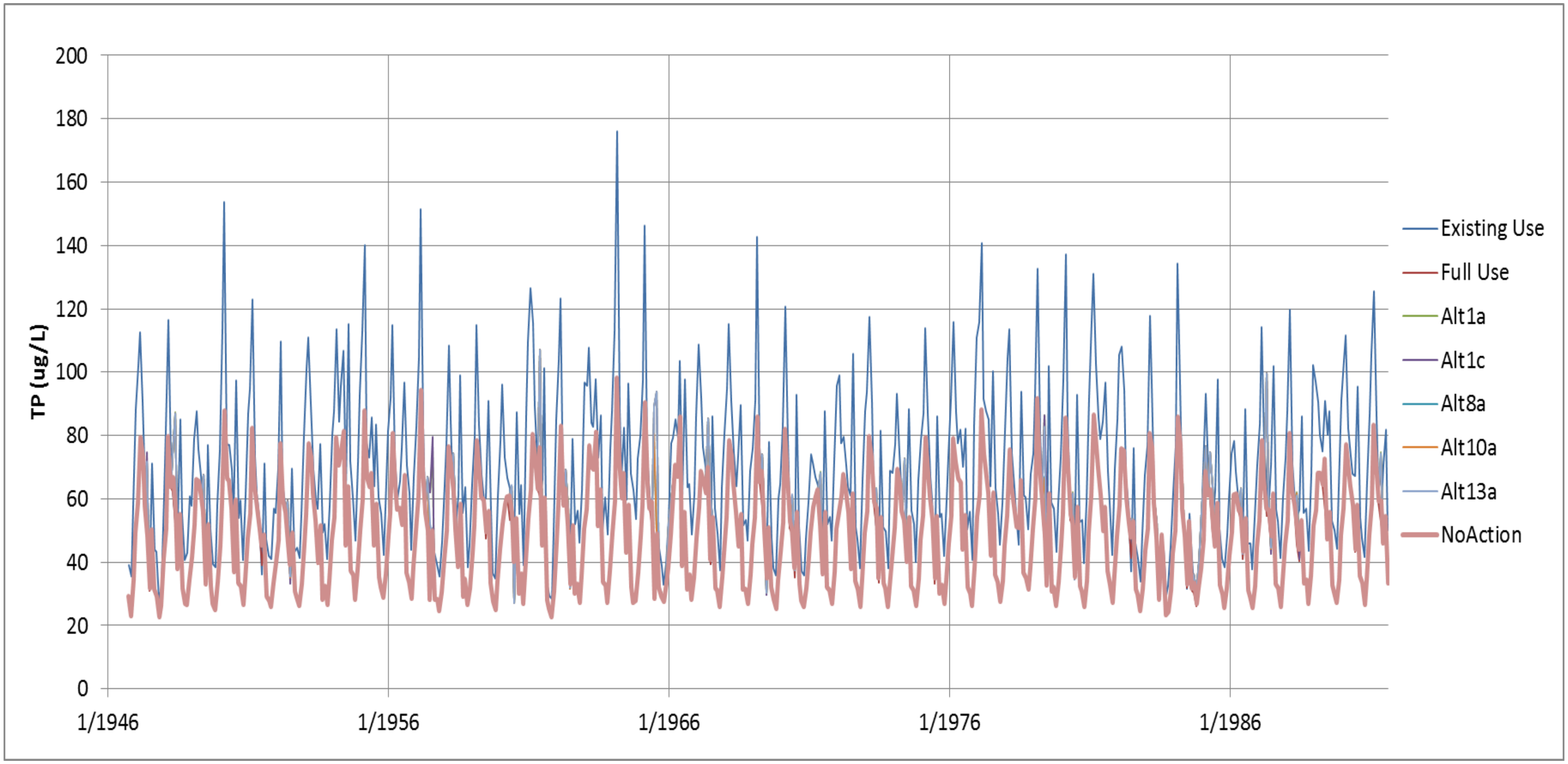


Figure E-4.7: Fraser River below Fraser Wastewater Treatment Plant – Modeled Results for Total Nitrogen

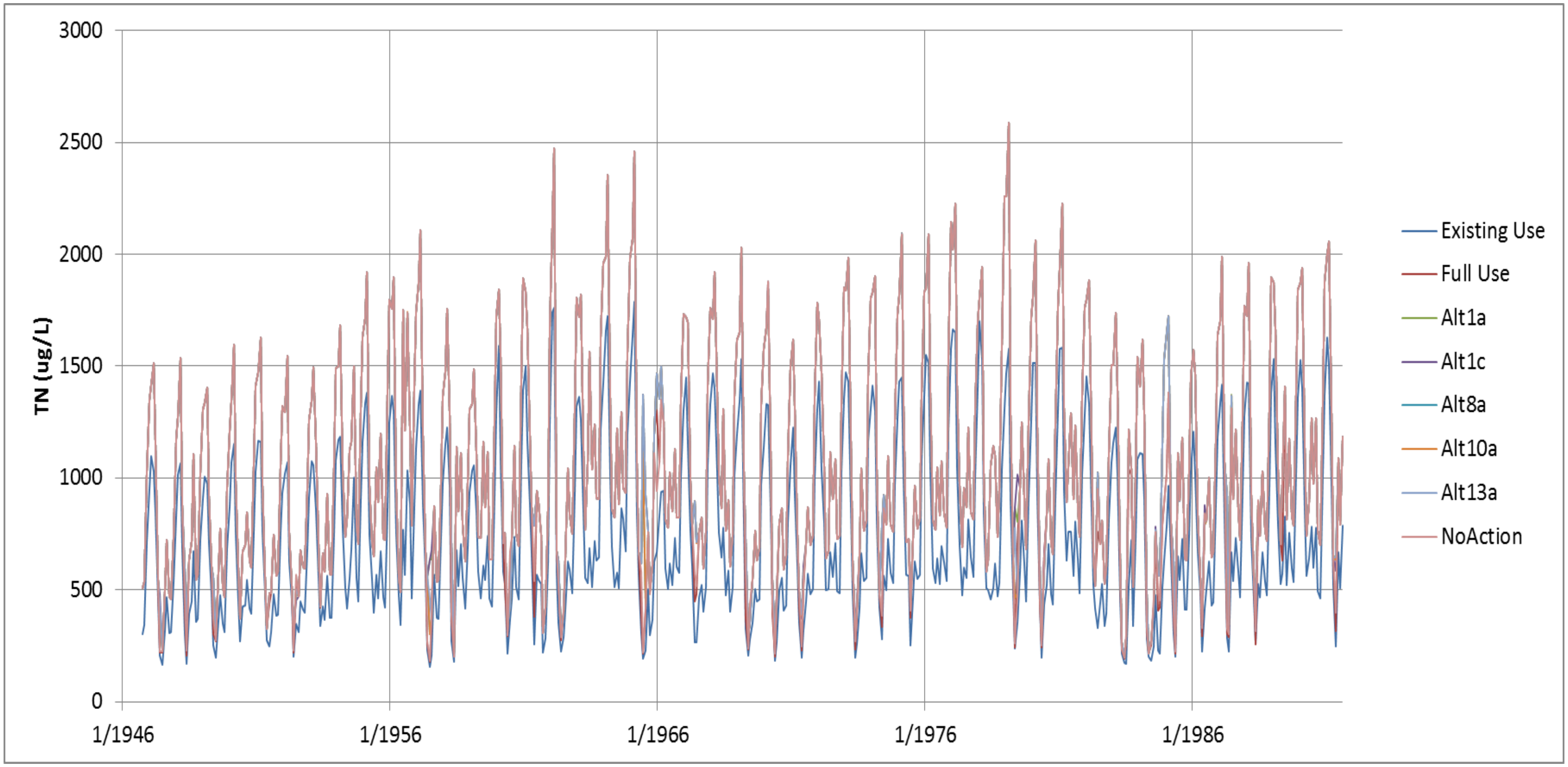


Figure E-4.8: Fraser River below Fraser Wastewater Treatment Plant – Modeled Results for Total Phosphorus

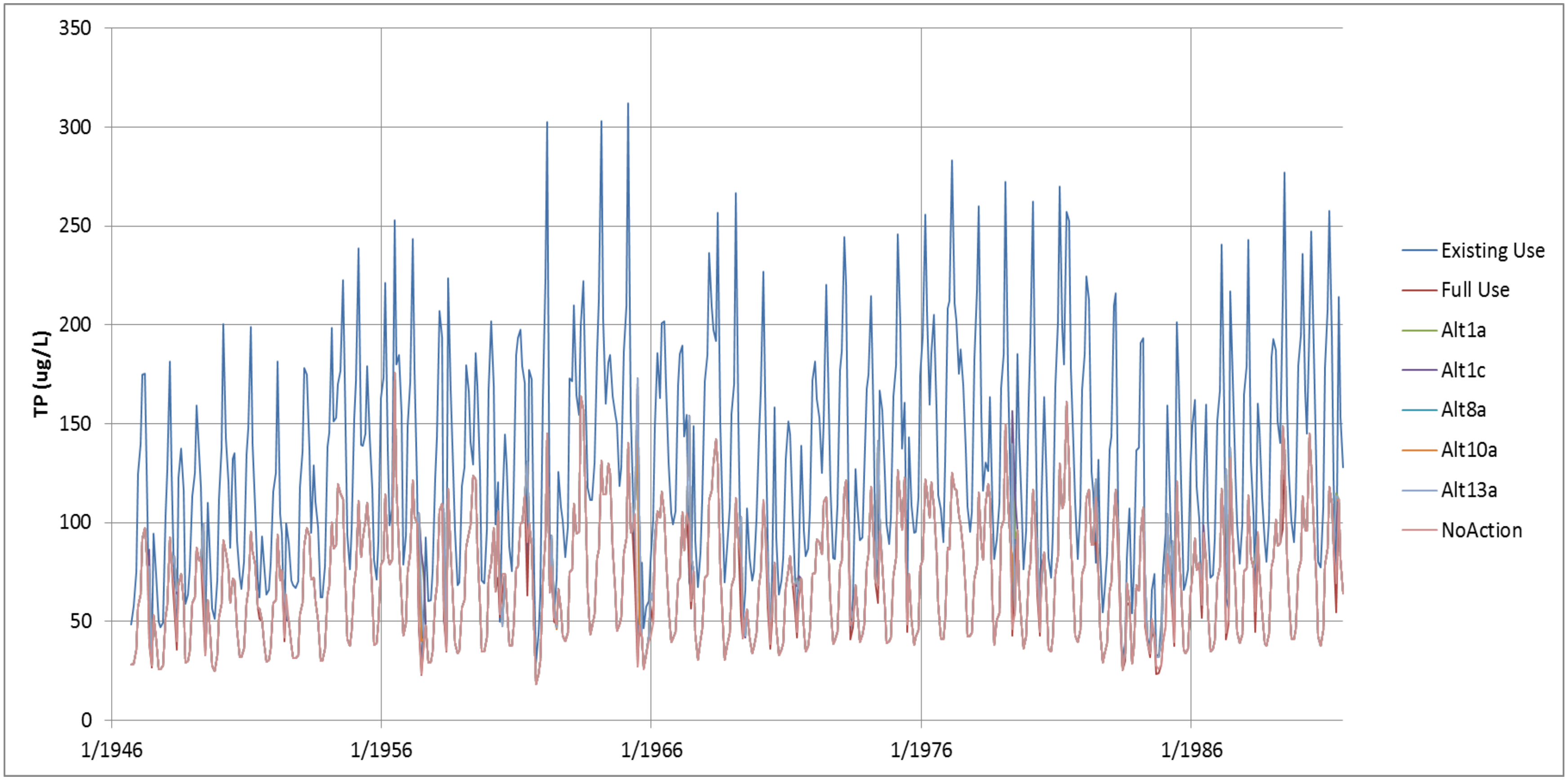


Figure E-4.9: Granby Reservoir – Modeled Results for Epilimnetic Chlorophyll *a*

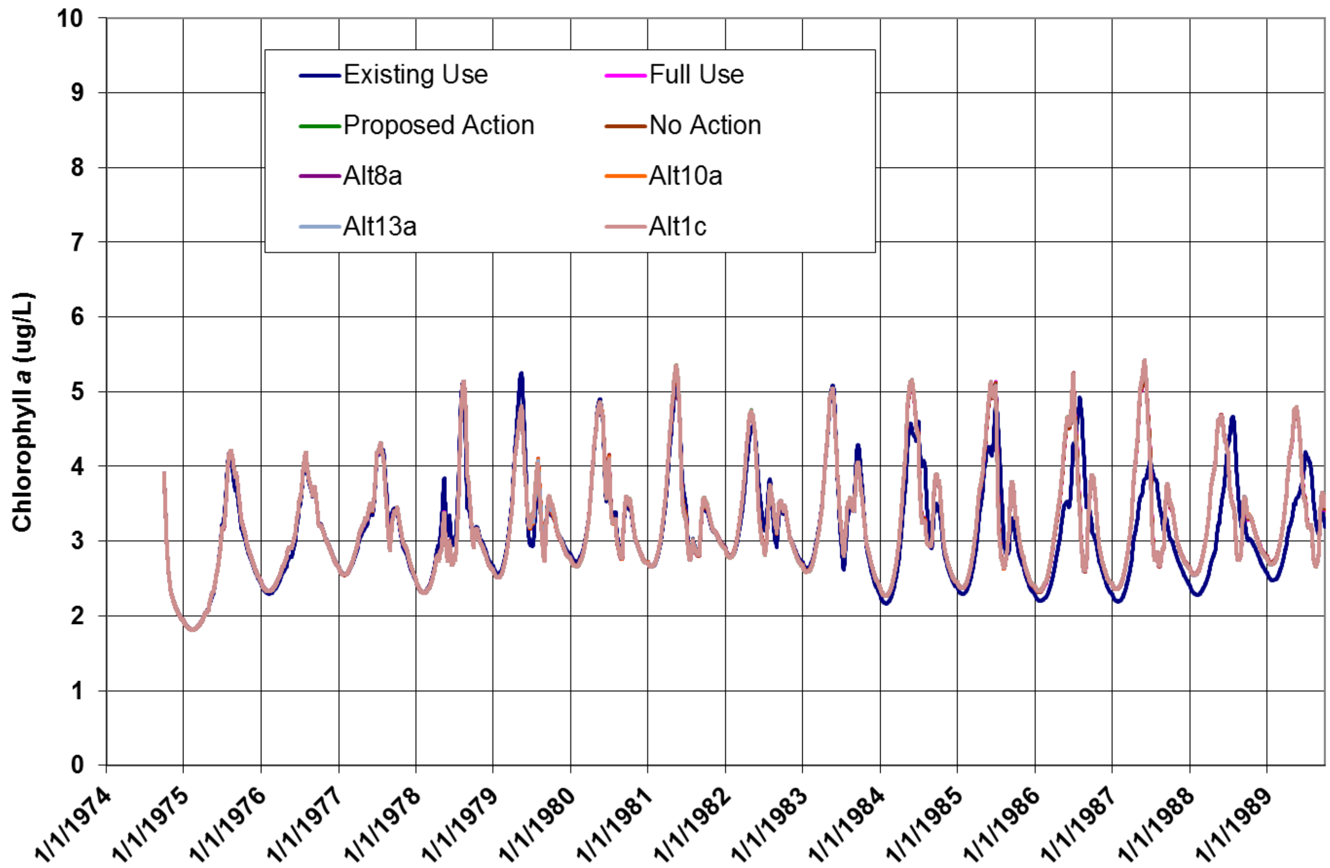


Figure E-4.10: Granby Reservoir – Modeled Results for Hypolimnetic Dissolved Oxygen

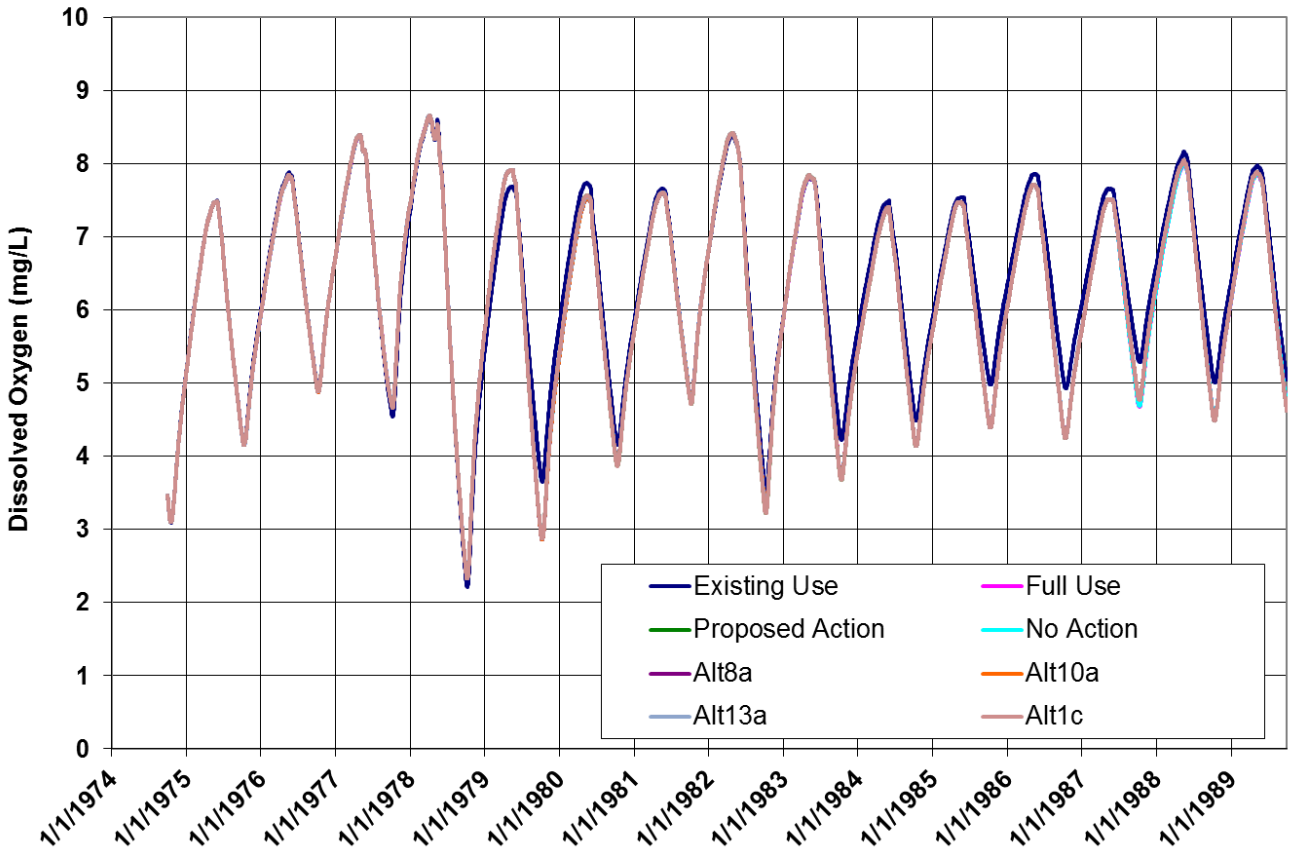


Figure E-4.11: Granby Reservoir– Modeled Results for Secchi Depth

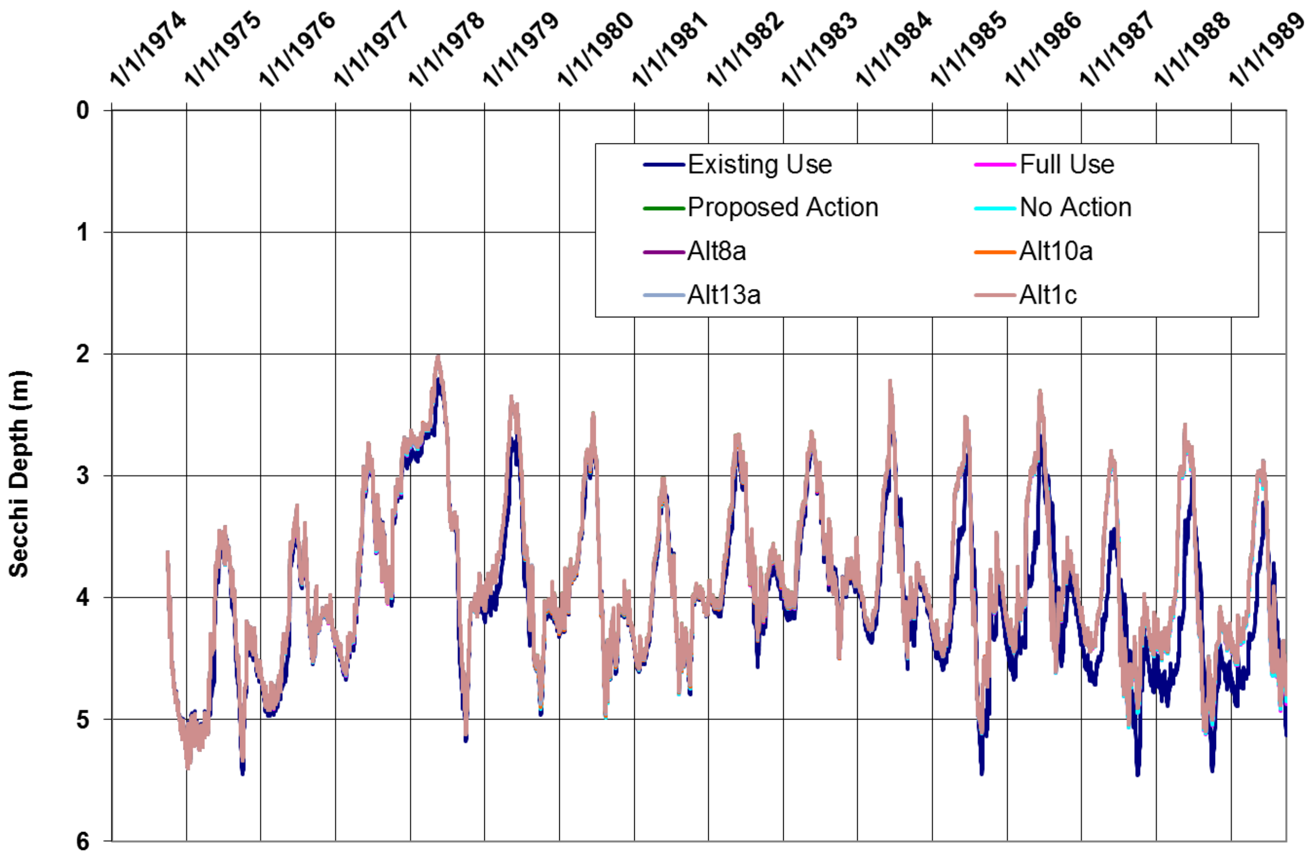


Figure E-4.12: Granby Reservoir – Modeled Results for Epilimnetic Total Nitrogen

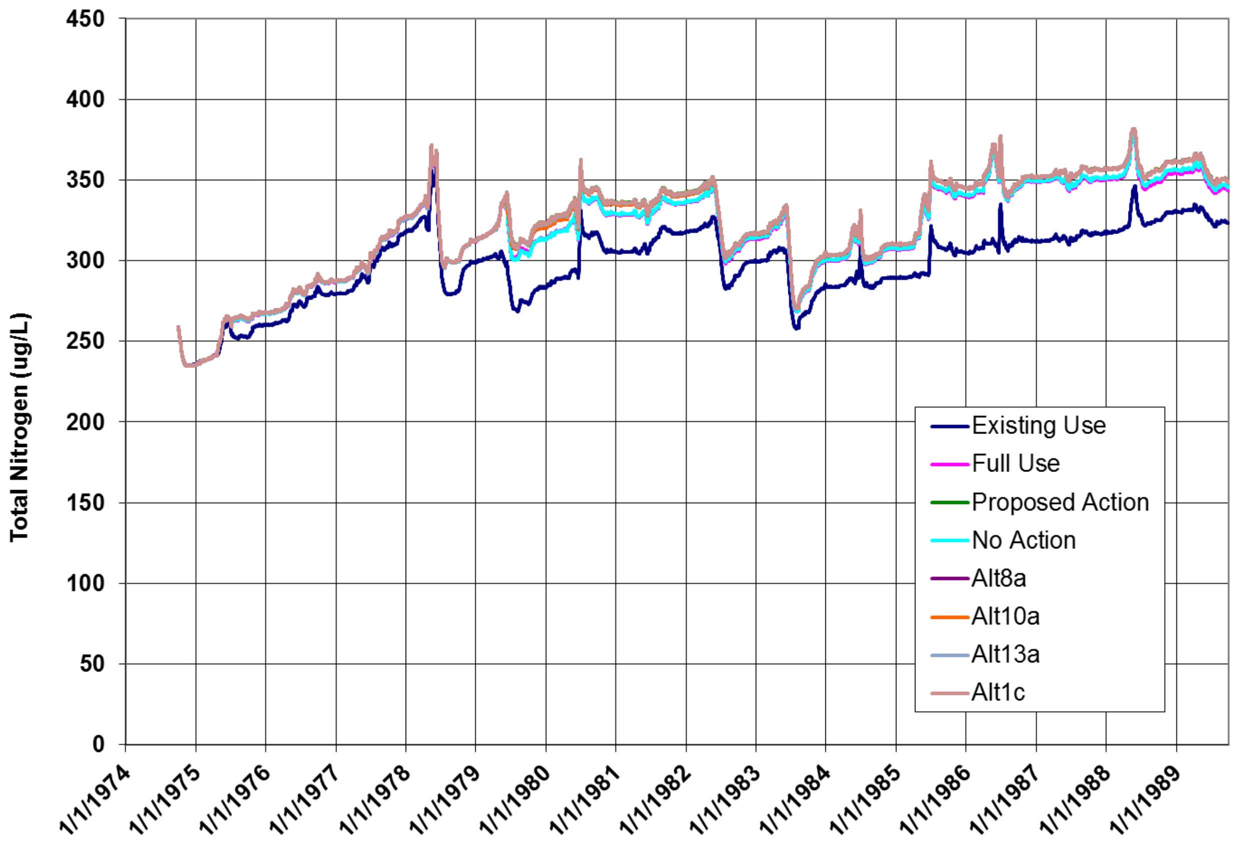


Figure E-4.13: Granby Reservoir – Modeled Results for Epilimnetic Total Phosphorus

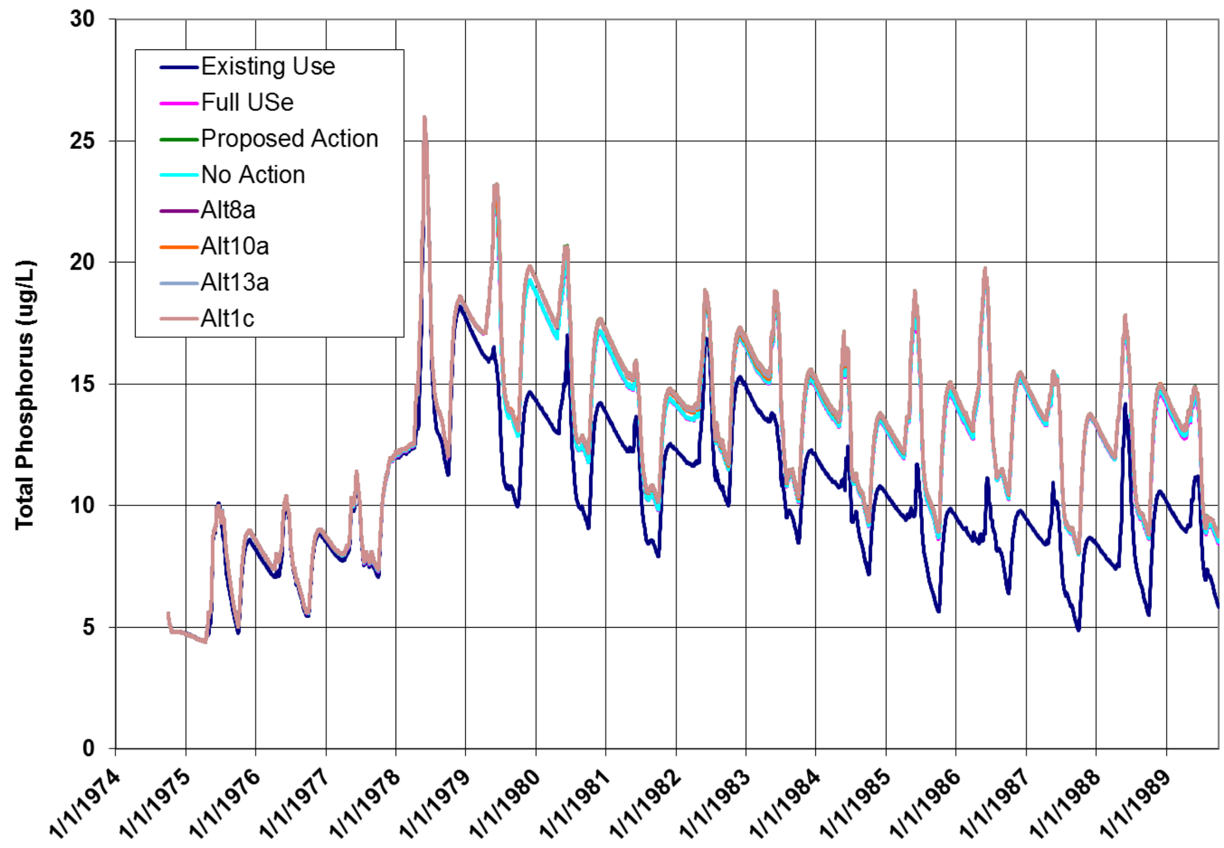


Figure E-4.14: Granby Reservoir – Modeled Results for Trophic State Index

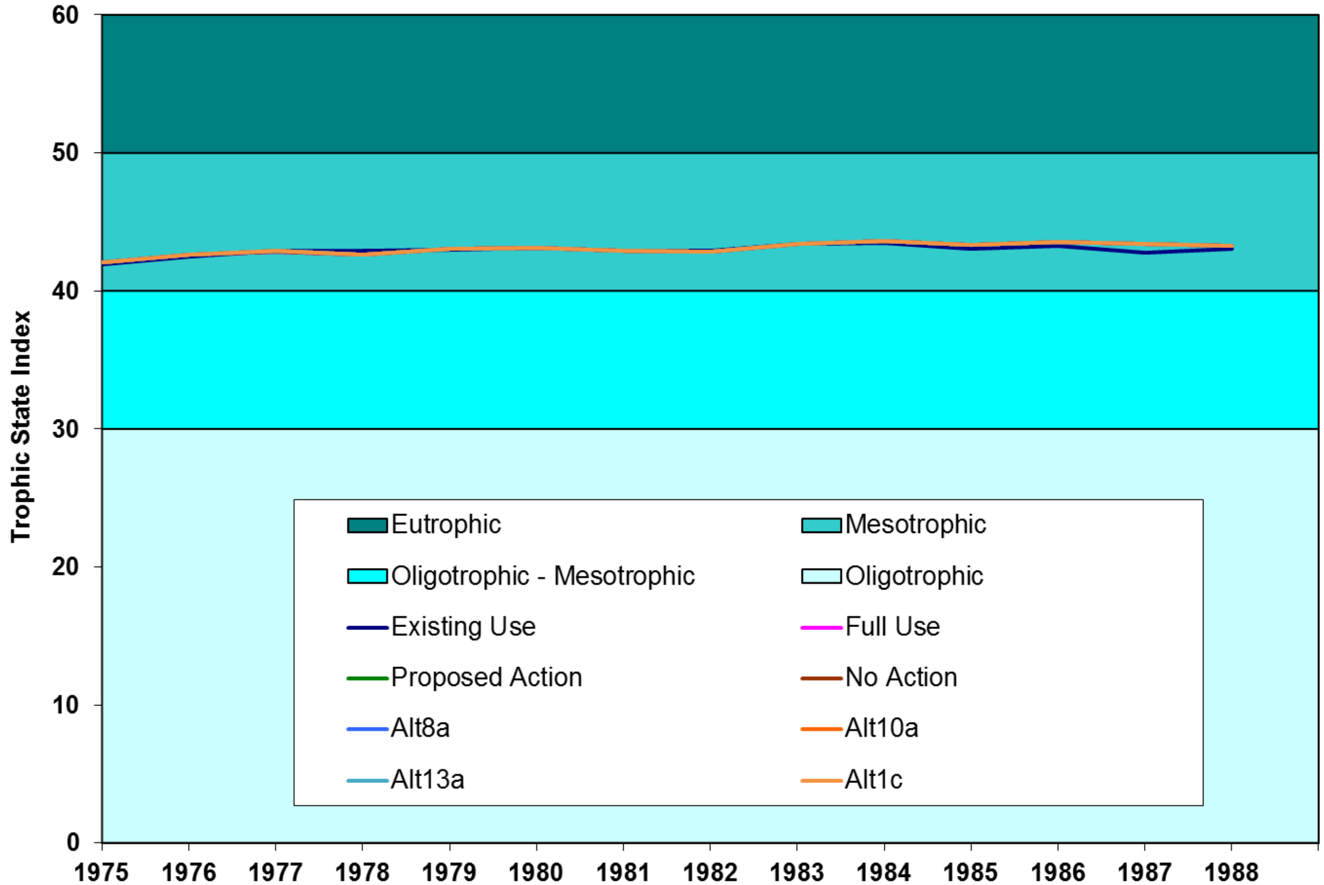


Figure E-4.15: Granby Reservoir – Modeled Results for Epilimnetic Total Suspended Solids

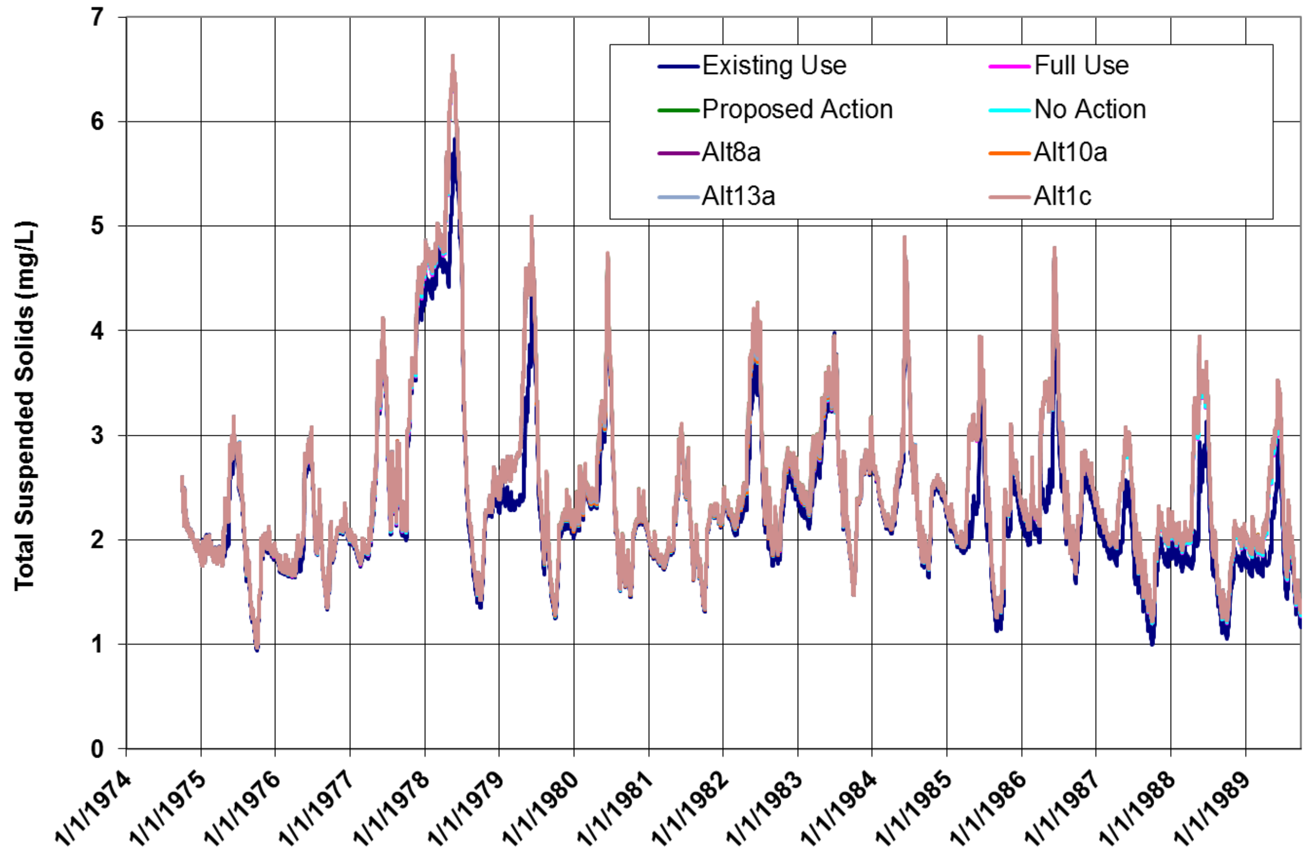


Figure E-4.16: Shadow Mountain Reservoir – Modeled Results for Chlorophyll *a*

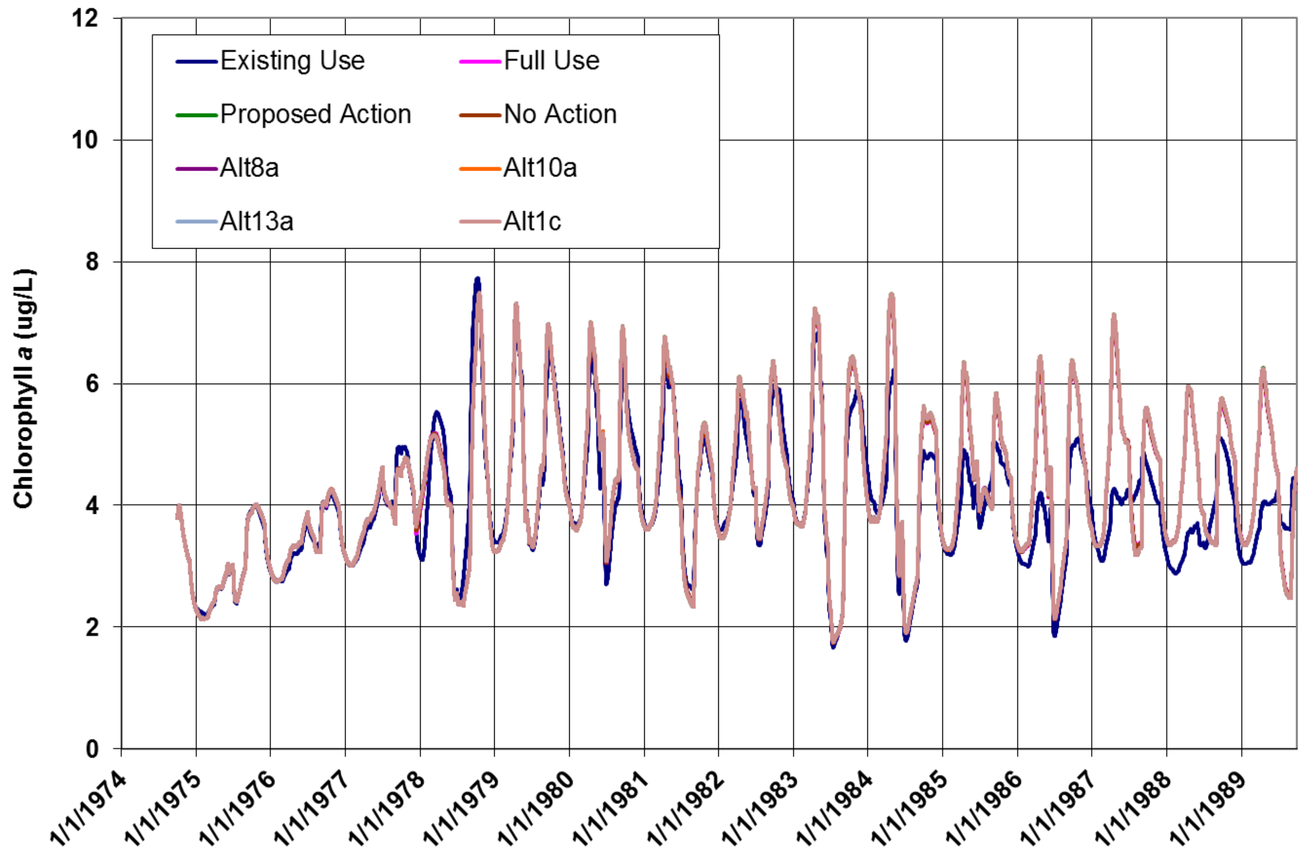


Figure E-4.17: Shadow Mountain Reservoir – Modeled Results for Dissolved Oxygen

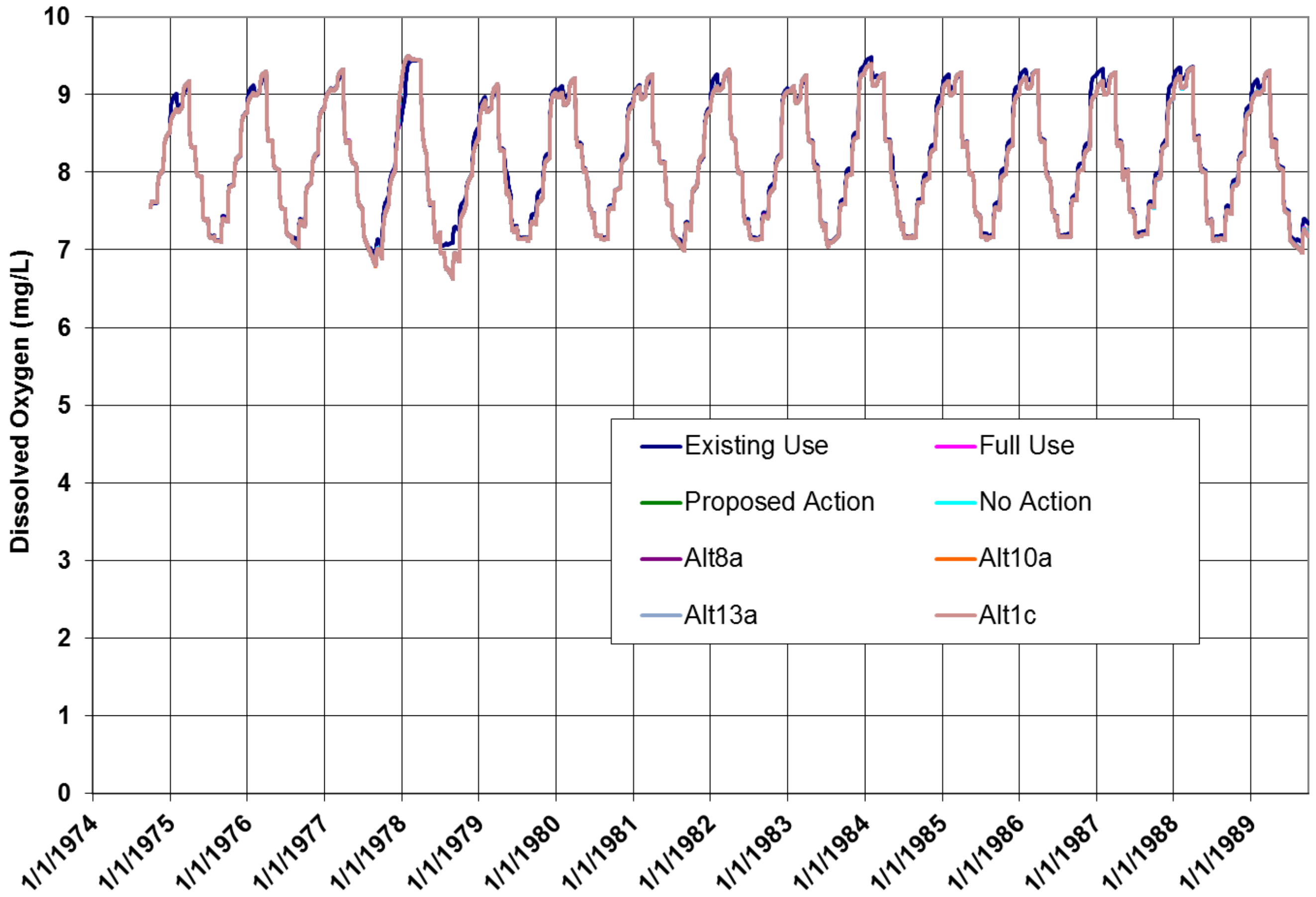


Figure E-4.18: Shadow Mountain Reservoir – Modeled Results for Secchi Depth

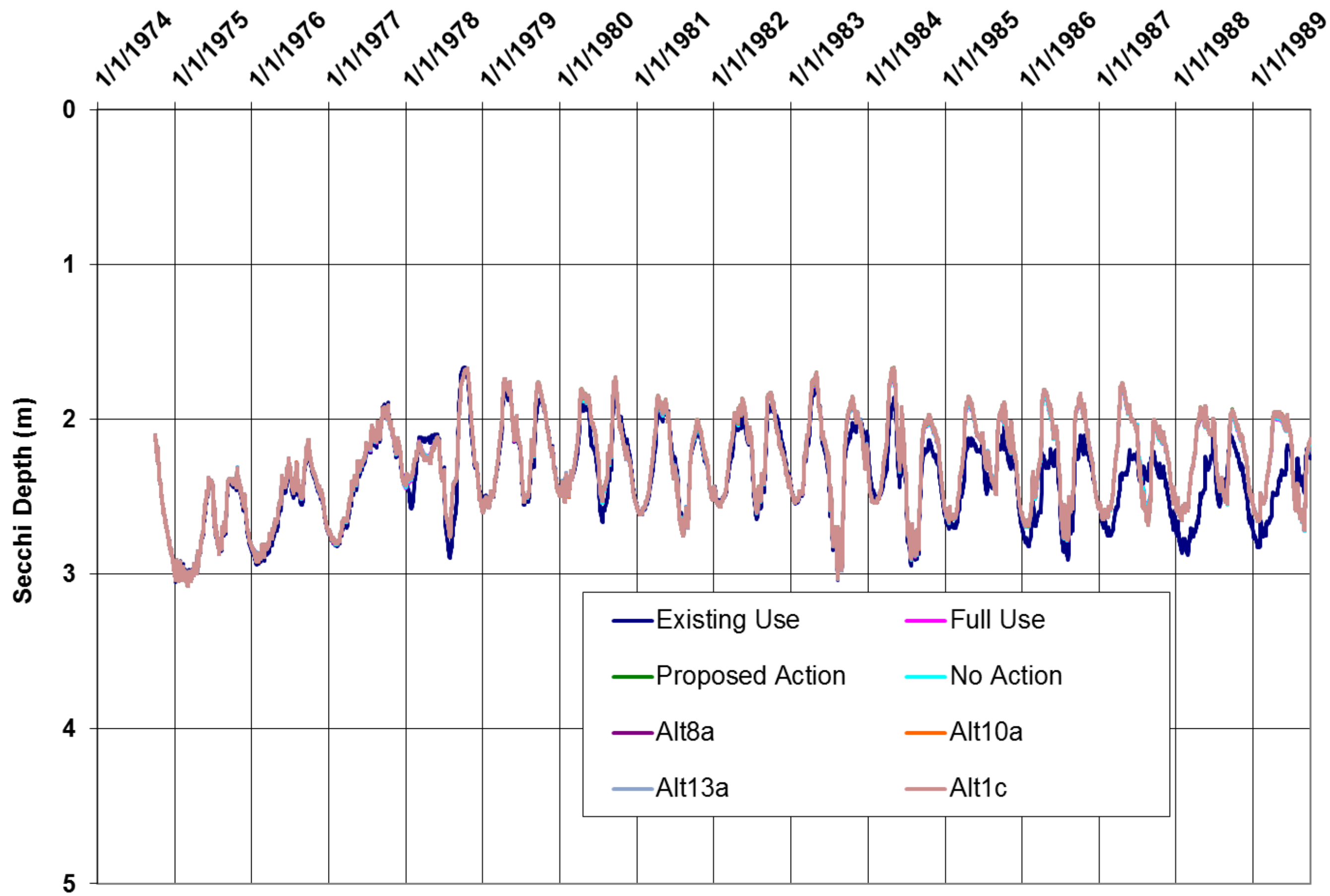


Figure E-4.19: Shadow Mountain Reservoir – Modeled Results for Total Nitrogen

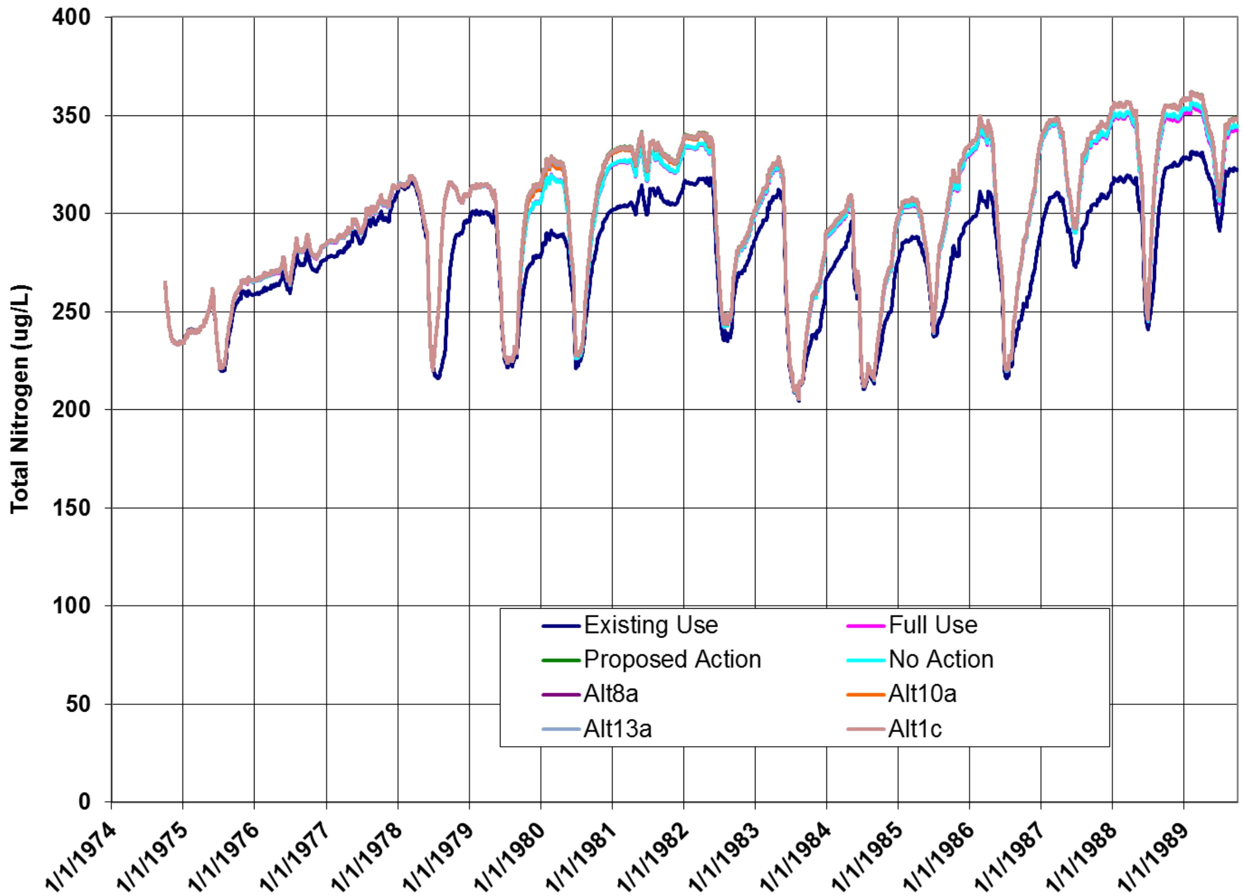


Figure E-4.20: Shadow Mountain Reservoir – Modeled Results for Total Phosphorus

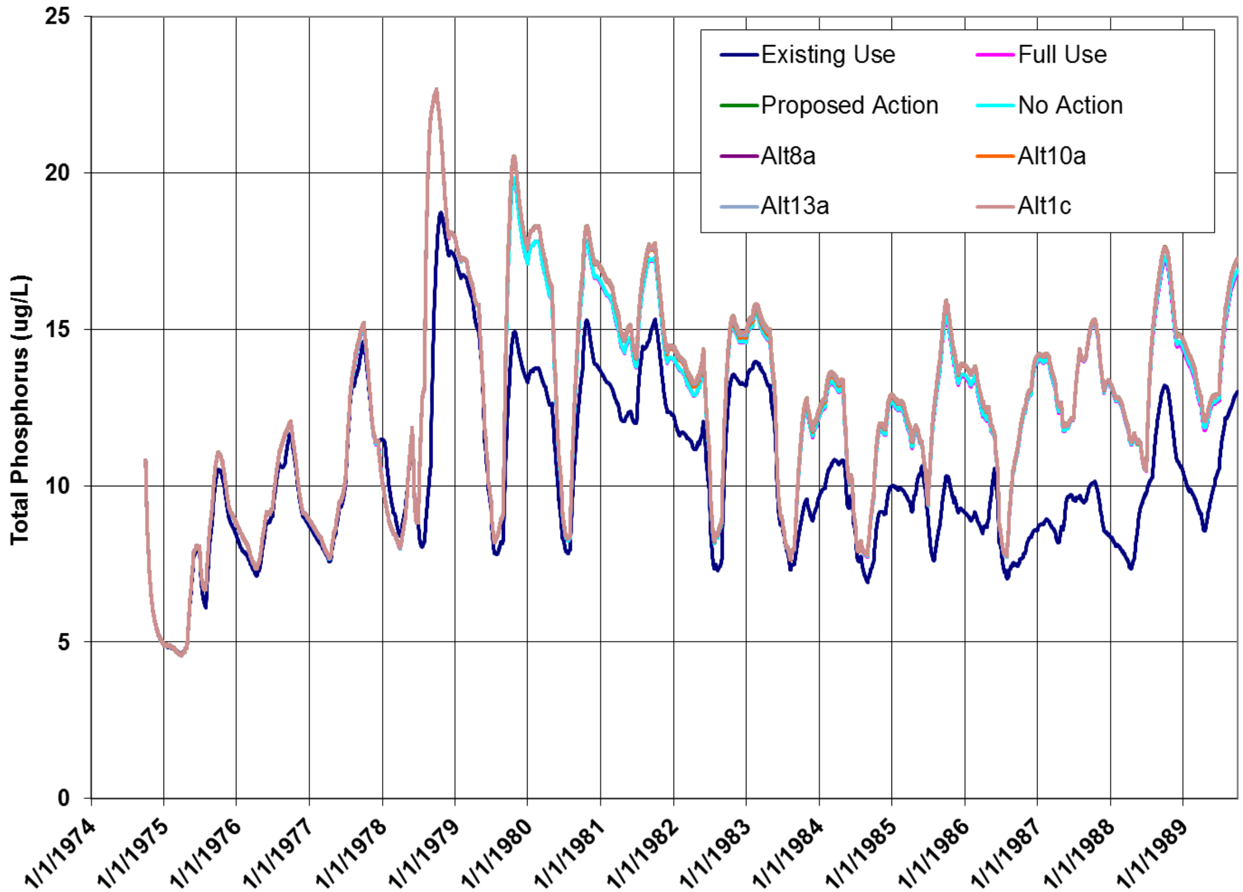


Figure E-4.21: Shadow Mountain Reservoir – Modeled Results for Trophic State Index

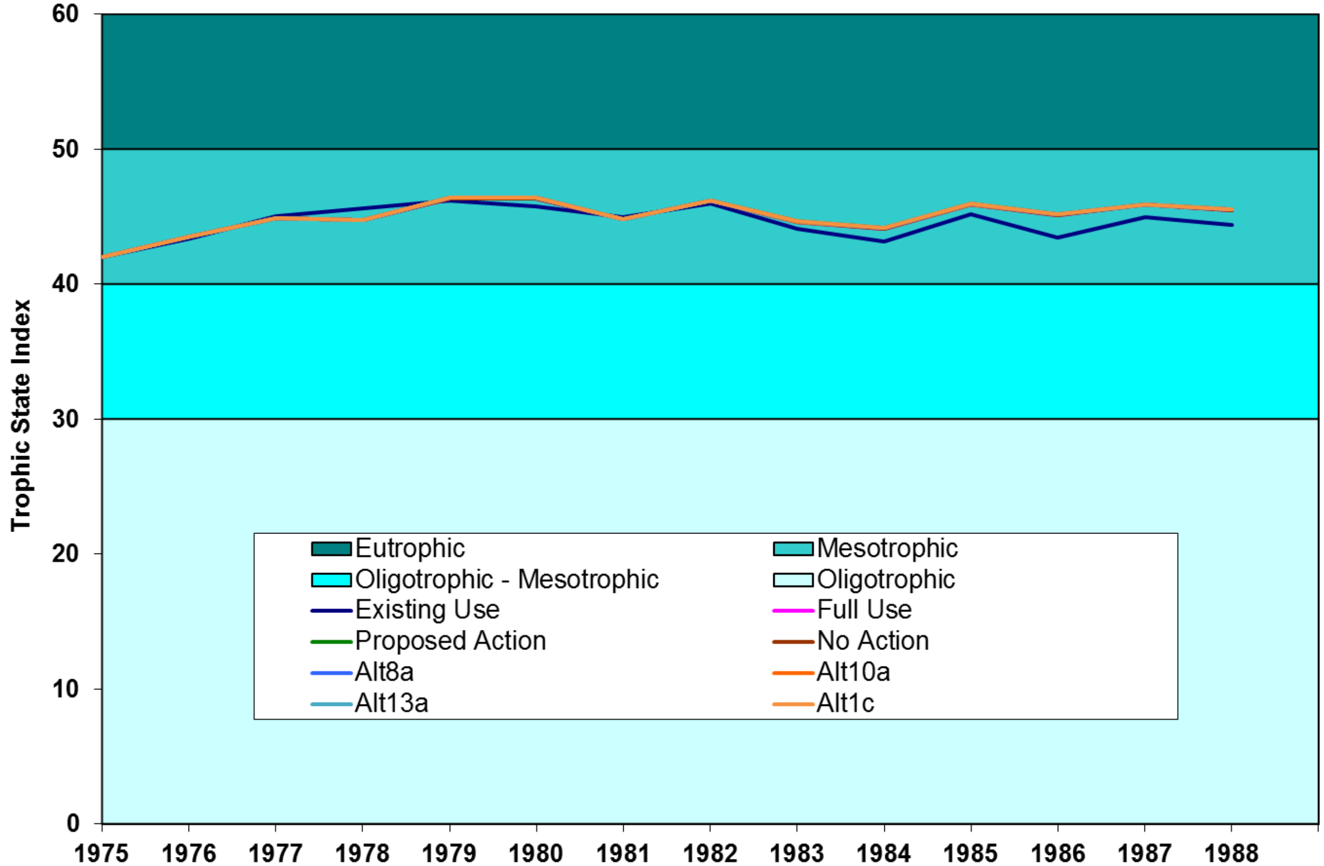


Figure E-4.22: Shadow Mountain Reservoir – Modeled Results for Total Suspended Solids

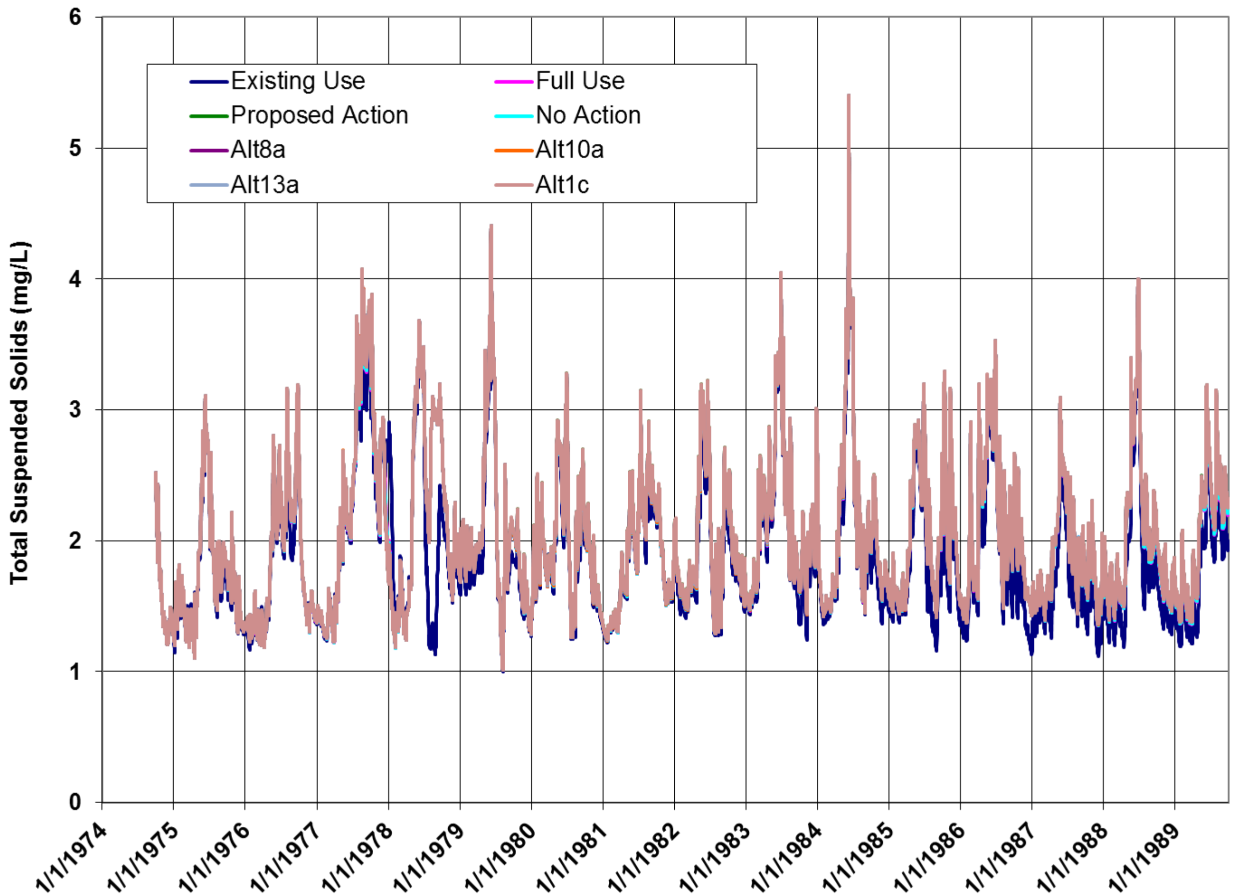


Figure E-4.23: Grand Lake – Modeled Results for Epilimnetic Chlorophyll *a*

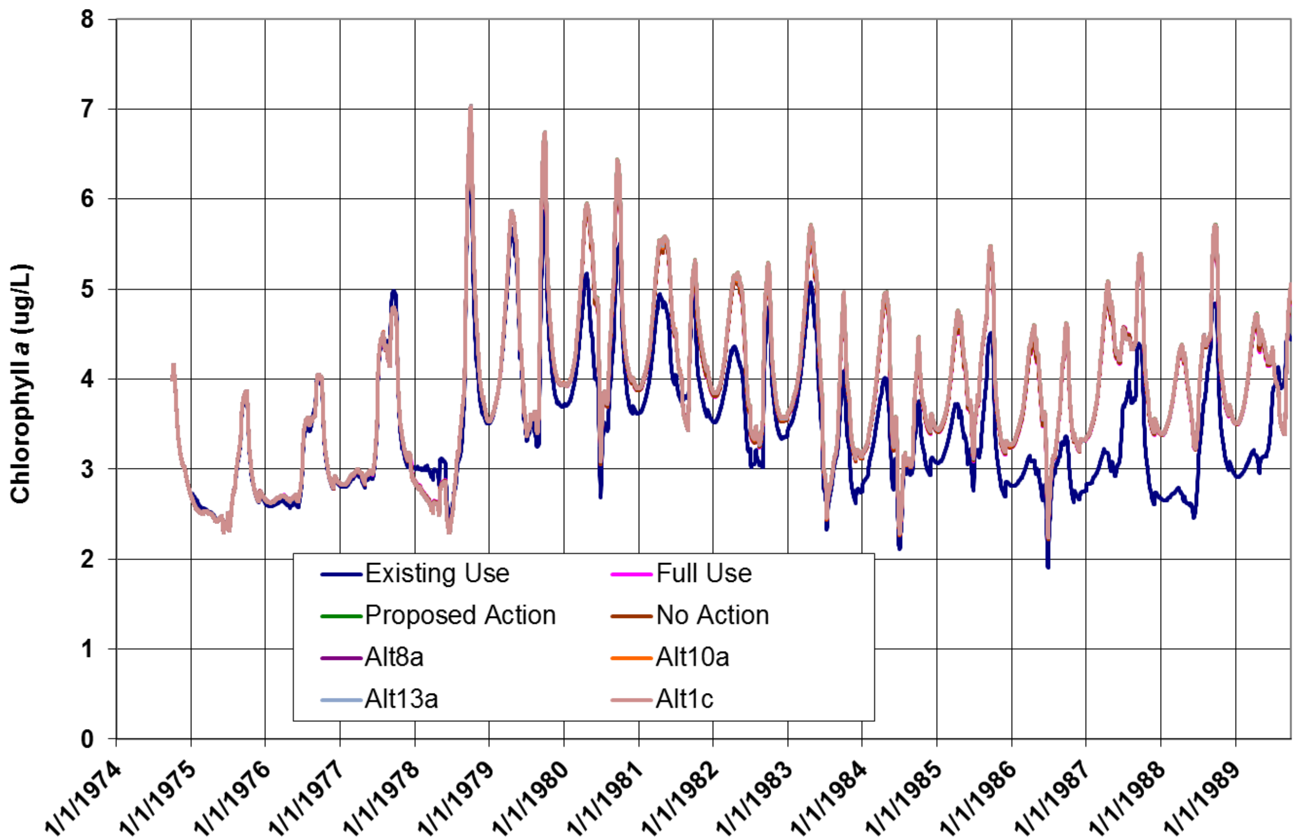


Figure E-4.24: Grand Lake – Modeled Results for Hypolimnetic Dissolved Oxygen

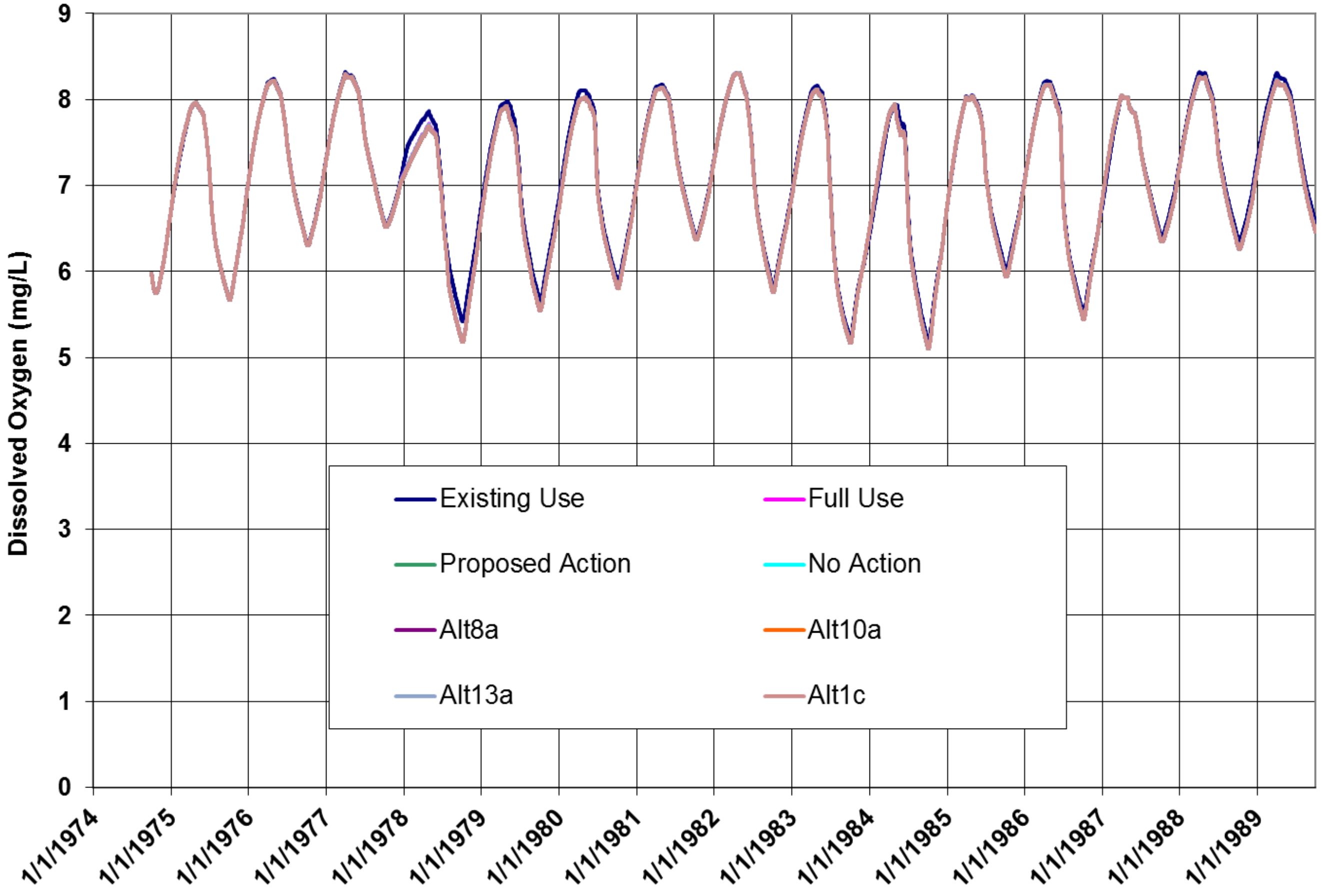


Figure E-4.25: Grand Lake – Modeled Results for Secchi Depth

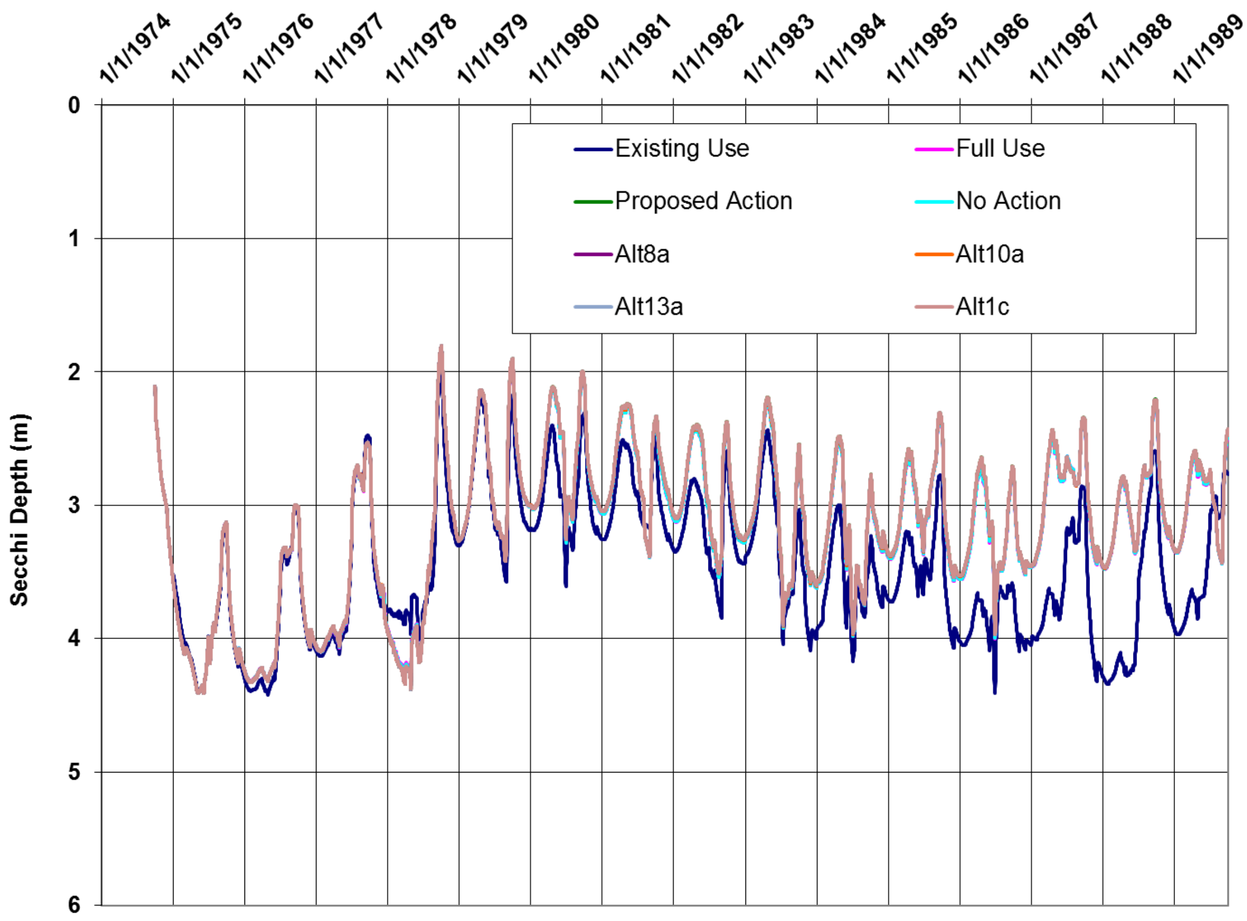


Figure E-4.26: Grand Lake – Modeled Results for Epilimnetic Total Nitrogen

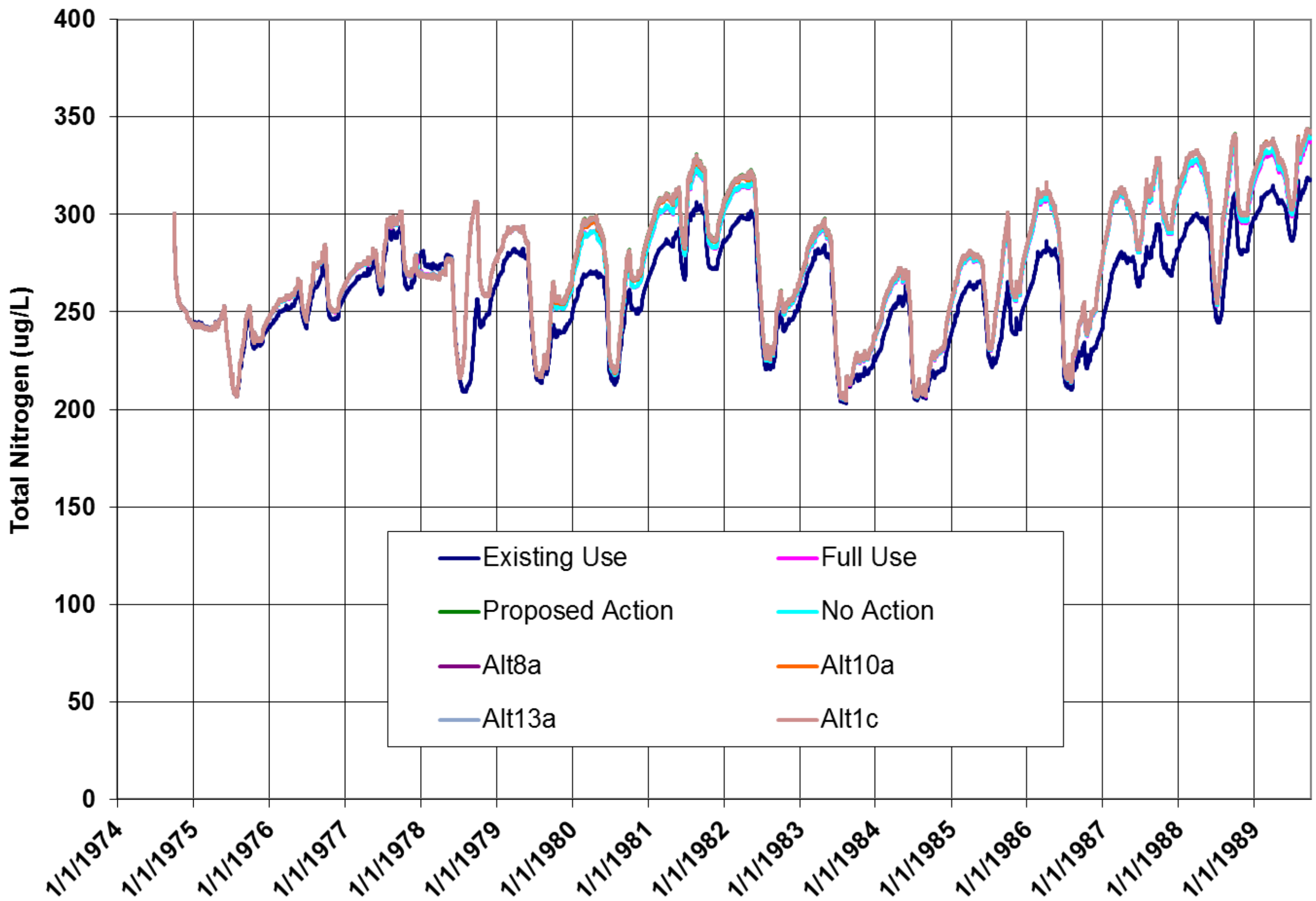


Figure E-4.27: Grand Lake – Modeled Results for Epilimnetic Total Phosphorus

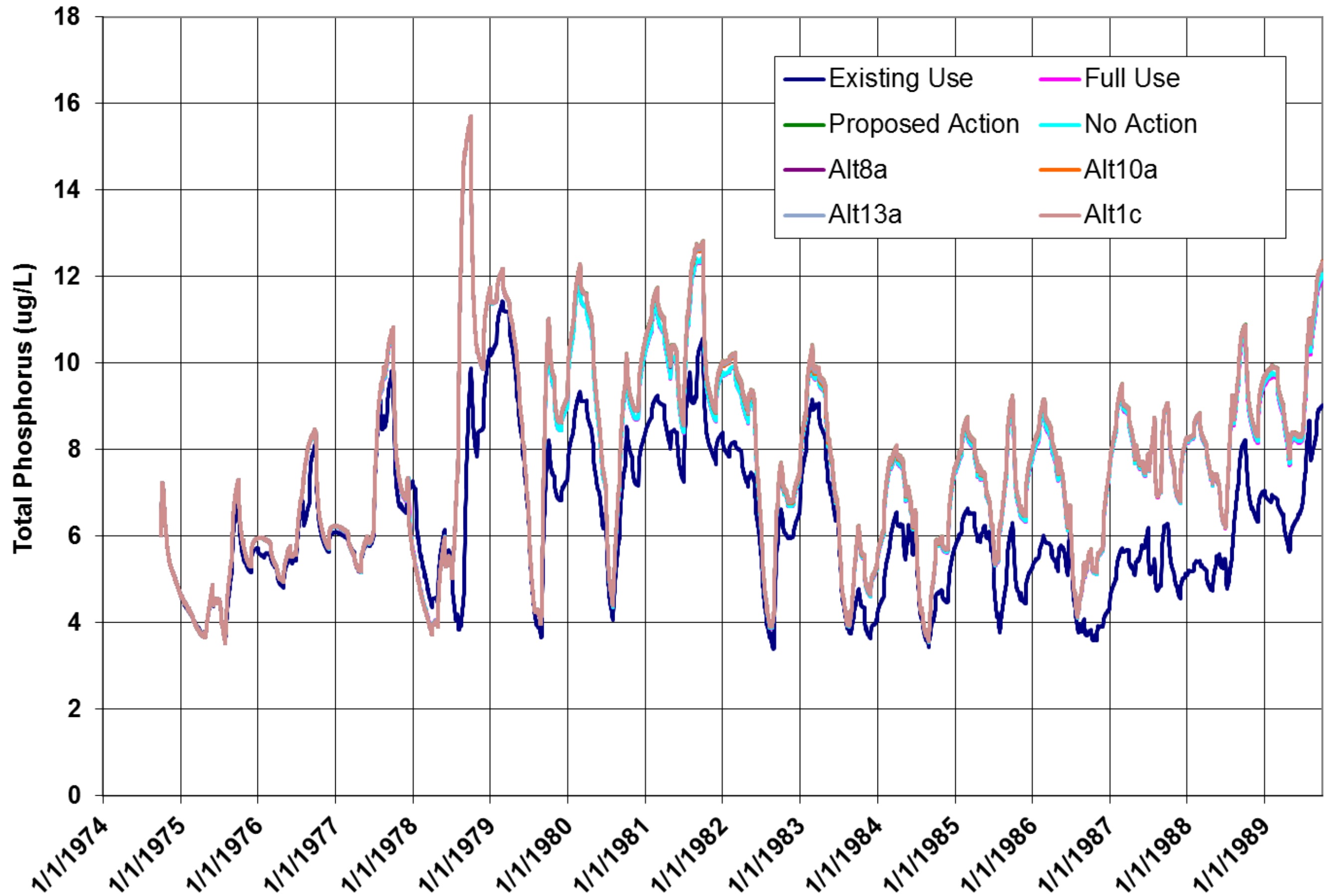


Figure E-4.28: Grand Lake – Modeled Results for Trophic State Index

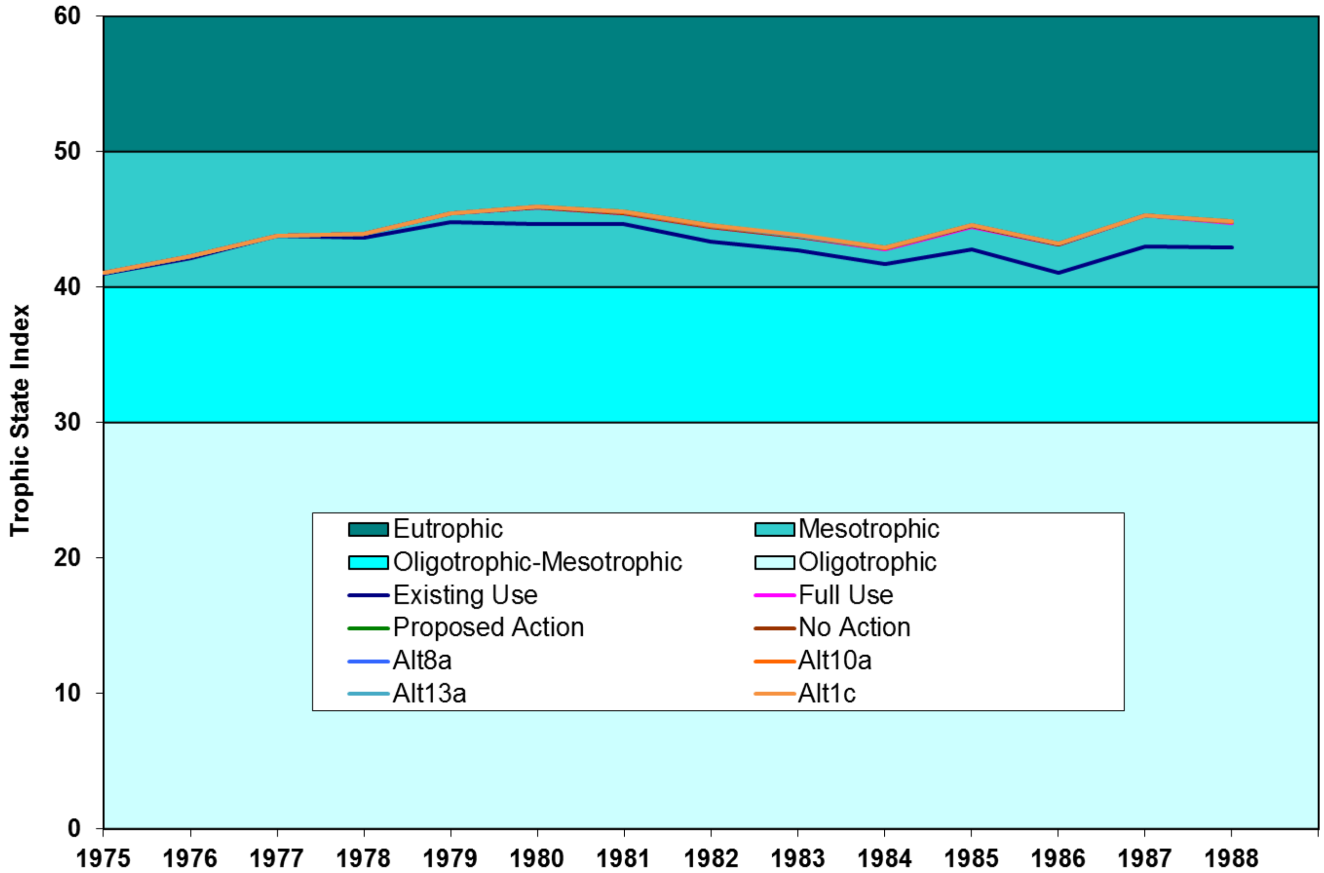
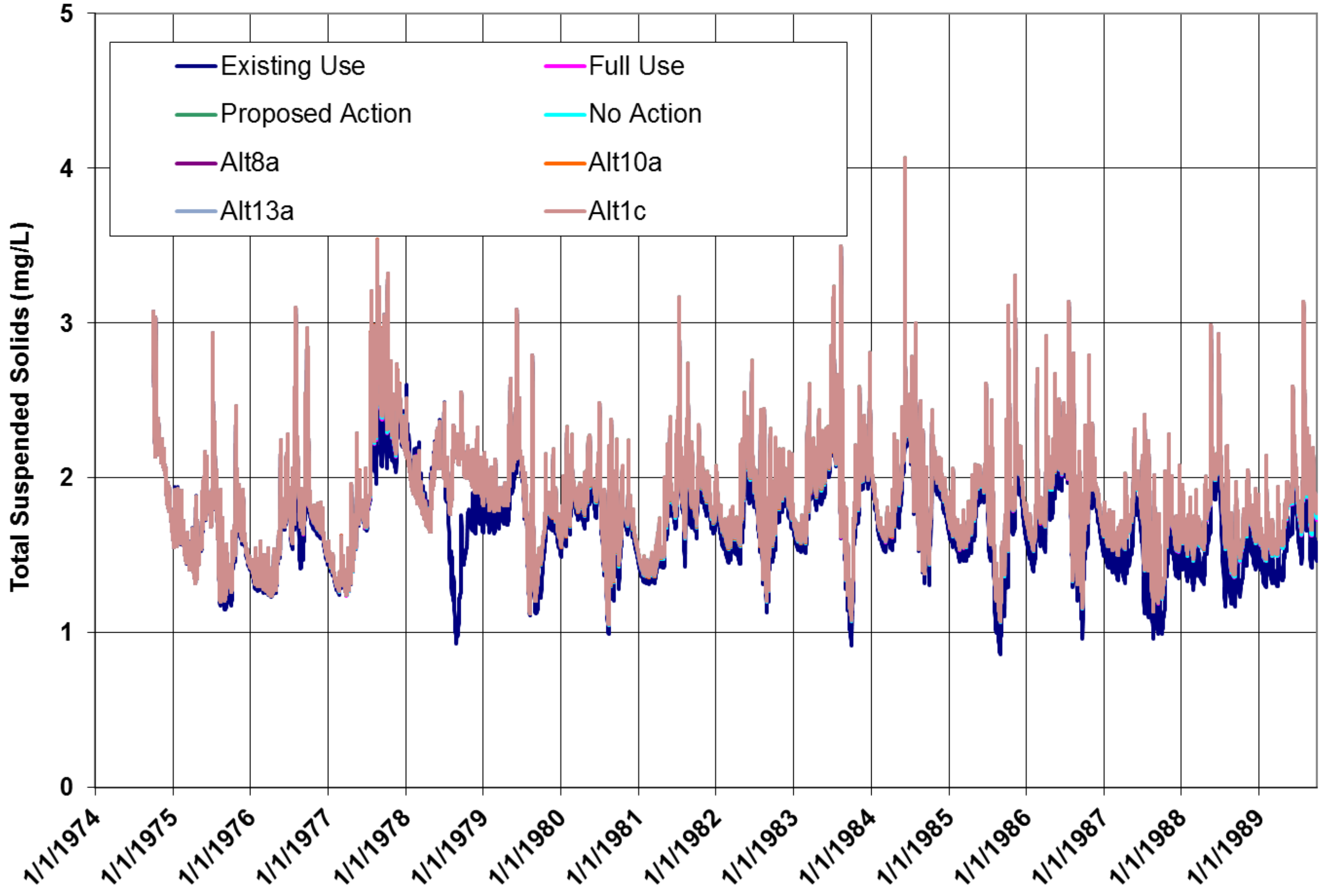


Figure E-4.29: Grand Lake – Modeled Results for Epilimnetic Total Suspended Solids



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Appendix E-5
Gross Reservoir Temperature Model: Model Development, Calibration, and Application for the Moffat Collection System EIS

GROSS RESERVOIR TEMPERATURE MODEL:
MODEL DEVELOPMENT, CALIBRATION, AND APPLICATION FOR THE MOFFAT COLLECTION SYSTEM EIS

Prepared for:
U.S. Army Corps of Engineers

Prepared by:
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Jean Marie Boyer, PhD, PE
Taylor Adams

Hydros Consulting

1731 Fifteenth St., Suite 103
Boulder, CO 80302

September 27, 2013

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ACRONYMS AND ABREVIATIONS

1A	PFEIS Proposed Alternative 1a
AF	Acre-ft
Alt1a	PFEIS Proposed Alternative 1a
Alt10a	PFEIS Proposed Alternative 10a
Alt13a	PFEIS Proposed Alternative 13a
Alt1c	PFEIS Proposed Alternative 1c
Alt8a	PFEIS Proposed Alternative 1a
AME	Absolute mean error
Base285	PFEIS Existing Supply /Existing Demand
C	Celsius
CDPHE	Colorado Department of Public Health and Environment
cfs	Cubic feet per second
EIS	Environmental Impact Statement
EP	East Portal
ft	Feet
F	Fahrenheit
GIS	Geographical Information System
m	Meters
Met	meteorologic
mph	Miles per hour
NREL	National Renewable Energy Labs
PACSM	Platte and Colorado Simulation Model
PFEIS	Preliminary Final Environmental Impact Statement
RMSE	Root mean squared error
TMDL	Total Maximum Daily Load
USACE	U.S. Army Corps of Engineers
Yr	Year

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1 INTRODUCTION

This report documents development and application of a two-dimensional hydrodynamic temperature model for Gross Reservoir. As described in the Preliminary Final Environmental Impact Statement for the Moffat Collection System Project (PFEIS; U.S. Army Corps of Engineers [USACE] 2012), Denver Water is proposing to enlarge Gross Reservoir by raising the dam height from 103.5 m to 141.6 m (340 ft to 465 ft). In comments on the PFEIS (CDPHE, 2012a), the Colorado Department of Public Health and Environment (CDPHE) expressed interest in seeing predictions in the Final Environmental Impact Statement (EIS) of the effects of the proposed enlargement on release temperatures to South Boulder Creek. The water-quality concern is that expansion of the reservoir could lead to colder release temperatures, resulting in aquatic life concerns in South Boulder Creek below the dam. To respond to these comments, a numerical model of Gross Reservoir was developed and applied.

The objective of the work described in this report is to develop and apply a numerical model to anticipate potential effects on outlet water temperatures of the proposed expansion of Gross Reservoir (PFEIS Proposed Alternative 1a [Alt1a]). This report does not attempt to interpret effects of the predicted changes to water temperature on aquatic life. Assessment of any aquatic-life impacts will be conducted by an aquatic life expert and included in the Final EIS.

This report is organized into five main sections and one appendix. The report is organized as follows:

- Section 1 is the introductory section.
- An overview of the findings from the review of existing relevant data is presented in Section 2. This section includes a brief discussion of findings from previous relevant studies of the reservoir.
- Model development and testing are documented in Section 3, including a description of the modeling software, model construction, and calibration.
- Model application results are presented and discussed in Section 4.
- A summary of the report, including findings and recommendations, is presented in Section 5.
- References cited in the report are listed in Section 6.
- Finally, Appendix A contains tabular results of daily outflow temperatures for the model simulations.

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2 BACKGROUND AND REVIEW OF EXISTING INFORMATION

Gross Reservoir is located in a deeply incised valley on South Boulder Creek in Boulder County, Colorado. The current dam crest elevation is 2,222 m (7,290 feet), impounding water from South Boulder Creek and its tributaries of Winiger Gulch, and Forsythe Canyon for a total drainage area of 92.8 square miles (MWH, 2005). Additionally, the reservoir stores water delivered to South Boulder Creek by the Moffat Tunnel, a trans-basin diversion collecting water from the Williams Fork and Fraser River basins. Currently, the reservoir has a storage capacity of 41,811 acre-feet (AF), and water is released through outlet works located near the bottom of the reservoir. The natural drainage area is primarily forested with areas of steep slopes and two population centers, the towns of Rollinsville and Pinecliffe (USACE, 2012). Much of the water released from Gross Reservoir is diverted to Ralston Reservoir via the South Boulder Diversion Canal about 4.5 river miles downstream of the dam. Key features and sampling locations are presented in Figure 1 from above the Moffat Tunnel to the South Boulder Diversion Canal. Detailed graphics of Gross Reservoir are presented in the DEIS, Chapter 3.

Gross Reservoir is classified by the State of Colorado for the following beneficial uses (CDPHE, 2013):

- Cold water aquatic life;
- Recreation;
- Water Supply; and
- Agriculture.

There are currently no temperature-related 303(d) listings for Gross Reservoir or South Boulder Creek (CDPHE, 2012b)[1].

Existing studies and data from Gross Reservoir and South Boulder Creek related to the issue of Gross Reservoir effects on South Boulder Creek water temperatures are described in the following subsection.

---

[1] The 303(d) list is a list of water bodies or stream/river segments where water-quality concerns indicate that technology-based effluent limitations and other required controls alone are not stringent enough to allow the segment to meet standards. The list is required by Section 303(d) of the federal Clean Water Act and identifies segments for which Total Maximum Daily Loads (TMDLs) must be developed.

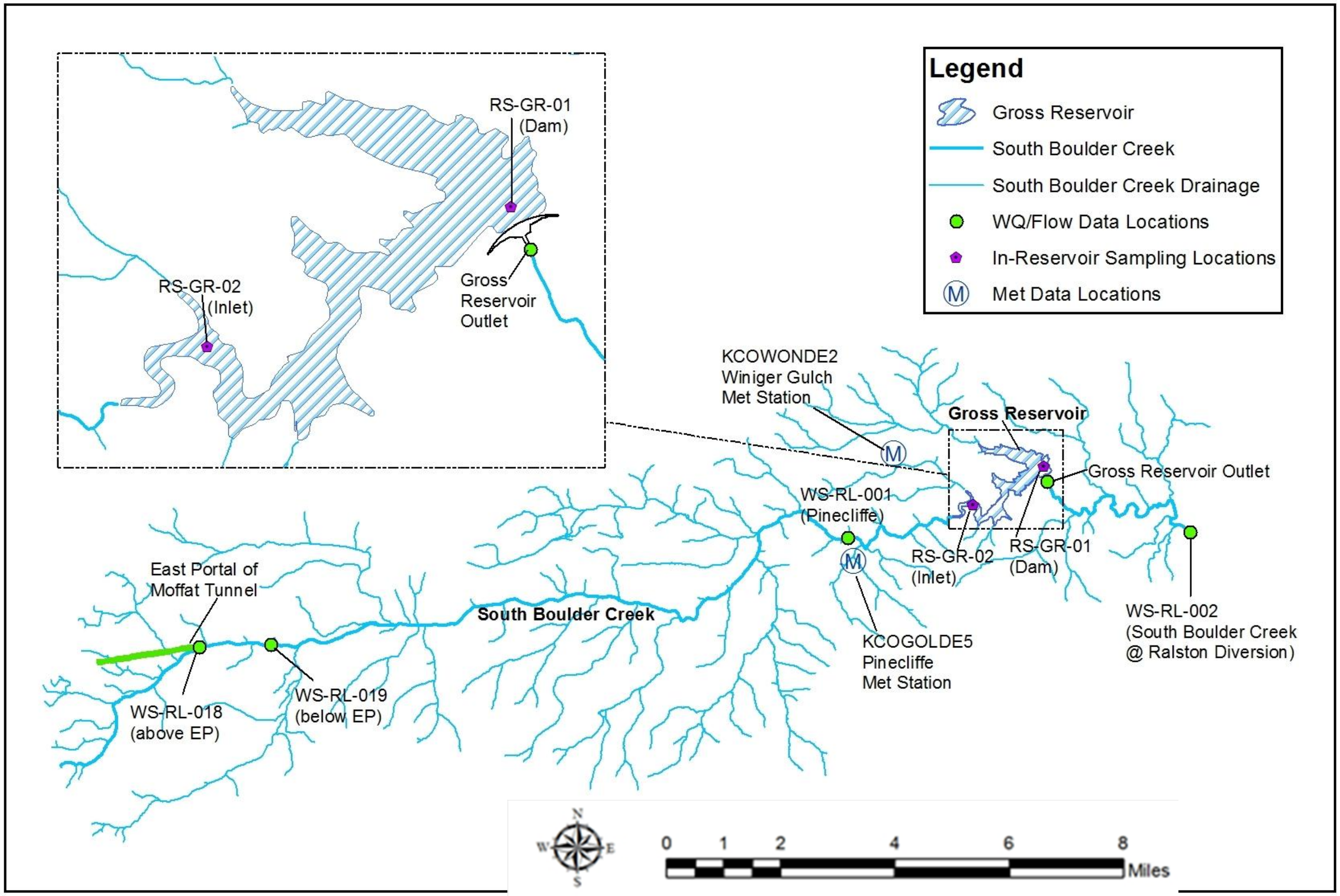

Figure 1. Moffat Tunnel to the South Boulder Diversion Canal

2.1 PREVIOUS STUDIES OF GROSS RESERVOIR TEMPERATURES

Only one previous study was found that focused on water temperature and Gross Reservoir. An empirical study of Gross Reservoir effects on South Boulder Creek temperature was completed in 1998 (Lewis and Saunders, 1998). The study assessed the effect of Gross Reservoir on temperatures in South Boulder Creek and the potential of a selective withdrawal system to provide warmer water to South Boulder Creek below the reservoir. There was a fairly limited dataset available at the time to support the assessment. The analysis relied primarily on two years of profile data, 1985 and 1997, as well as 23 inlet and outlet temperature observations collected between 1973 and 1980. Profile data were used to calculate a heat budget to support the selective withdrawal warming calculations. Inlet and outlet temperature data were evaluated to assess the observed effect of the reservoir on temperatures in South Boulder Creek.

The study concluded that Gross Reservoir did not significantly cool waters in South Boulder Creek relative to inflow temperatures. Specifically, the analysis found an average of roughly 0.5 °C of cooling in the Creek occurring due to the reservoir from the beginning of June to mid-September. Unfortunately, the directly-paired data used for this assessment were limited to nine observations from June and September collected between 1973 and 1980. This question is reassessed in the following subsection (Section 2.2) with more recent data.

The study also concluded that selective withdrawal only had the potential to provide a small amount of warming to waters downstream of the reservoir (approximately 2 °C on average). This assessment was based on the current size and configuration of the reservoir, using empirical estimates of warming rates and thermal mass. The authors explain that the high outflow rates relative to the estimated rate of warming explain this result, though the empirical approach and limited available data add to uncertainty.

2.2 REVIEW OF OBSERVED DATA

Observed hydrologic, meteorological, and water temperature data were reviewed to develop a conceptual understanding of the system prior to numerical model development. The following subsections present summaries of the findings from review of those datasets.

2.2.1 Hydrology

Gross Reservoir is a managed water body that collects runoff from South Boulder Creek and two small tributaries, Winiger Gulch and Forsythe Canyon. Additionally, water from the Fraser Basin and Williams Fork are diverted to the reservoir through the Moffat Tunnel, which flows into South Boulder Creek upstream of the reservoir. Based on data provided by Denver Water, a daily water balance was developed for the reservoir for 2000-2012. Daily inflow and outflow rates from that water balance are presented in Figure 2. The figure also shows Moffat Tunnel flow rates.

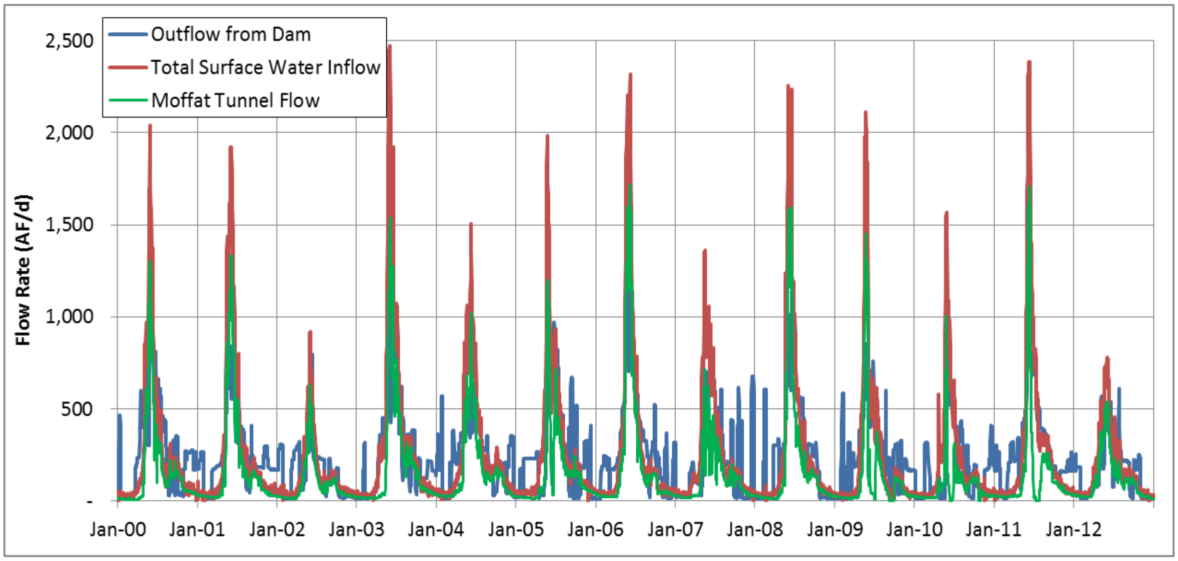

Figure 2. Inflow and Outflow Rates at Gross Reservoir (2000-2012)

As shown in Figure 2, inflow rates show the seasonal pattern of a dominant snowmelt hydrograph each year, typically peaking in late May or early June. Outflow rates also tend to be highest during the peak of the snowmelt runoff hydrograph; however, outflow exceeds inflow in fall and winter months. Moffat Tunnel flows make up roughly 60% of the surface water inflows. Direct precipitation, evaporation, and seepage comprise less than 1% each of the inflows or outflows from the reservoir each year.

Water levels in Gross Reservoir vary annually by roughly 7 to 27 m (23 to 90 ft), depending on operations. Observed daily water surface elevations from 2000 through 2012 are plotted in Figure 3. Generally, water is released through summer, fall, and winter months, resulting in the minimum annual water level in early spring. Spring inflows then refill the reservoir by early summer.

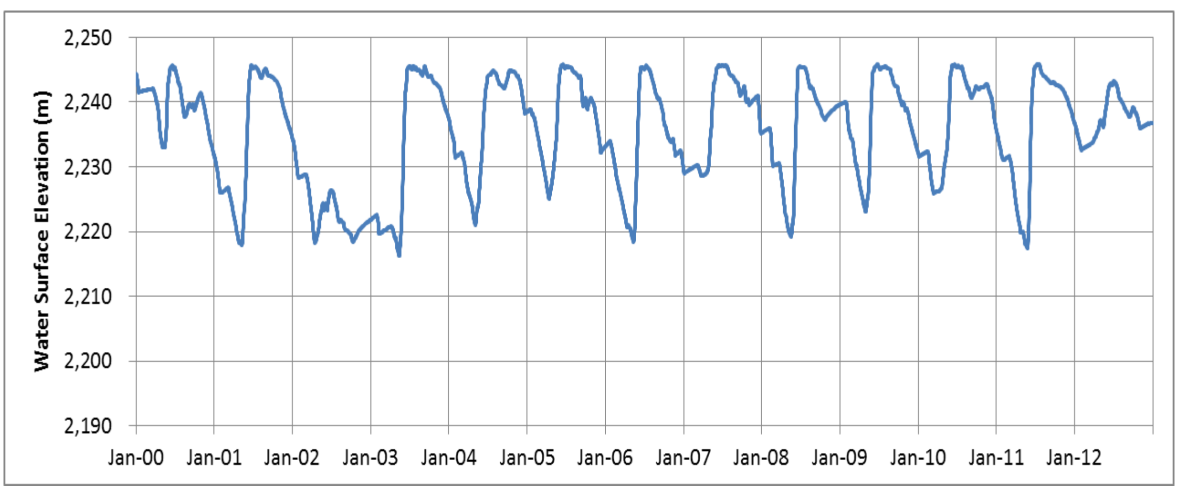

Figure 3. Water Surface Elevation for Gross Reservoir (2000-2012)

Based on outflow rates and reservoir contents, hydraulic residence time was estimated on a calendar-year basis. Annual average residence time between 2000 and 2012 varied between 90 days and 197 days (Figure 4), with an average residence time of 120 days when assessed over the full study period. These simple calculations reflect annual average residence time and assume complete mixing, which may not be a good assumption for Gross Reservoir during all seasons. The hydrodynamic model will better simulate mixing and resulting residence times.

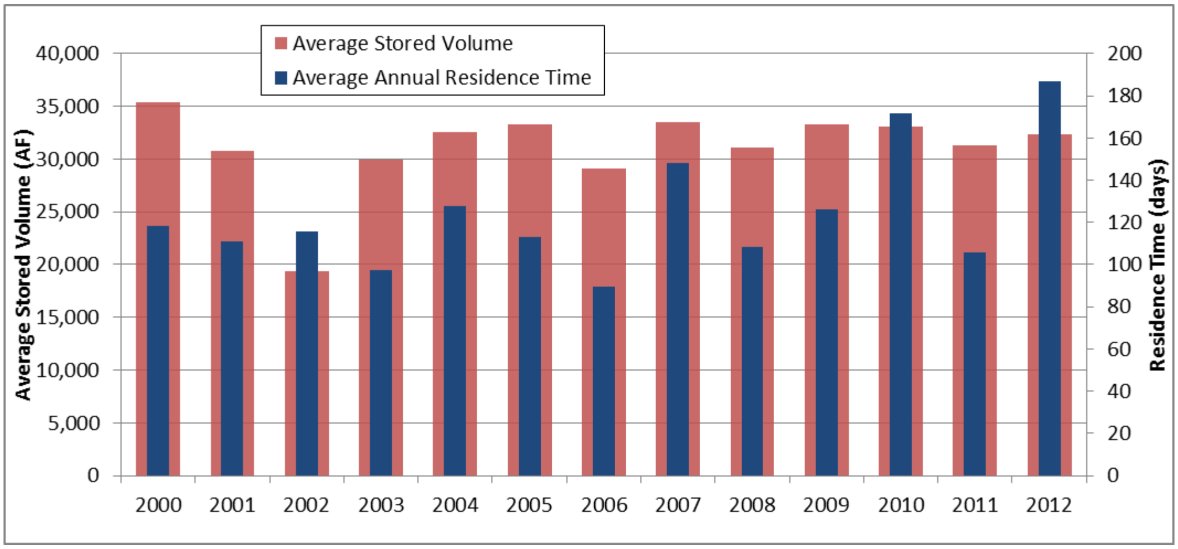

Figure 4. Calendar-Year Hydraulic Residence Time and Average Contents for Gross Reservoir (2000 - 2012)

2.2.2 Meteorology

Weather conditions can be an important driving force affecting reservoir mixing and temperature patterns. Key parameters include air temperature, precipitation, wind speed, wind direction, and solar radiation. In the following discussion, data are presented for the years 2000 through 2012, or the full available record if the full 2000-2012 period is unavailable.

Weather data are collected at several stations near Gross Reservoir. The following data were compiled for use in this project:

- Pinecliffe Met Data (KCOGOLDE5)
    - 5-minute data for air temperature, wind speed, wind direction, dew point, and cloud cover (available from 2009 to 2012);
    - Located approximately 3.9 miles southwest of the reservoir dam (elevation 8,324 ft); see Figure 1.
- Winiger Gulch Met Data (KCOWONDE2)
    - 15-minute data for air temperature, wind speed, wind direction, and dew point (available from 2010 to 2012);
    - Located approximately 3.2 miles west of the reservoir dam (elevation 8,222 ft); see Figure 1.
- Gross Reservoir Dam Met Data (provided by Denver Water)

   - Daily minimum and maximum air temperature, and precipitation (available from 1976 through 2012);
   - Located at the reservoir dam.
- NREL (National Renewable Energy Labs) – M2 Tower Solar Radiation Data
   - Hourly solar radiation data -total hemispheric shortwave irradiance (available from 1996 to 2012);
   - Located at the NREL Wind Technology Center approximately 7 miles east southeast of the reservoir dam (elevation 6,086 ft).

2.2.2.1 Air Temperature

Comparison of air temperature data from the high-frequency met stations to the daily minimum and maximum temperatures observed at the dam led to selection of the Pinecliffe (KCOGOLDE5) met station as the primary air temperature and dew point data location for this effort. Average maximum summer air temperatures from the Winiger Gulch (KCOWONDE2) met station were significantly colder (~8˚F [~4.4˚C] lower) than those at the other two locations. Missing data (~5% of the full dataset) from the Pinecliffe station were in-filled using monthly correlation-based equations to translate Winiger Gulch temperatures, when available.

The compiled air temperature dataset shows consistent seasonal patterns from year to year. Figure 5 presents daily minimum and daily maximum air temperatures at the Gross Reservoir dam from 2000 through 2012. For this period, the highest observed temperature was 94˚F (34˚C) in 2012, and the lowest was -24˚F (-31˚C) in 2011.

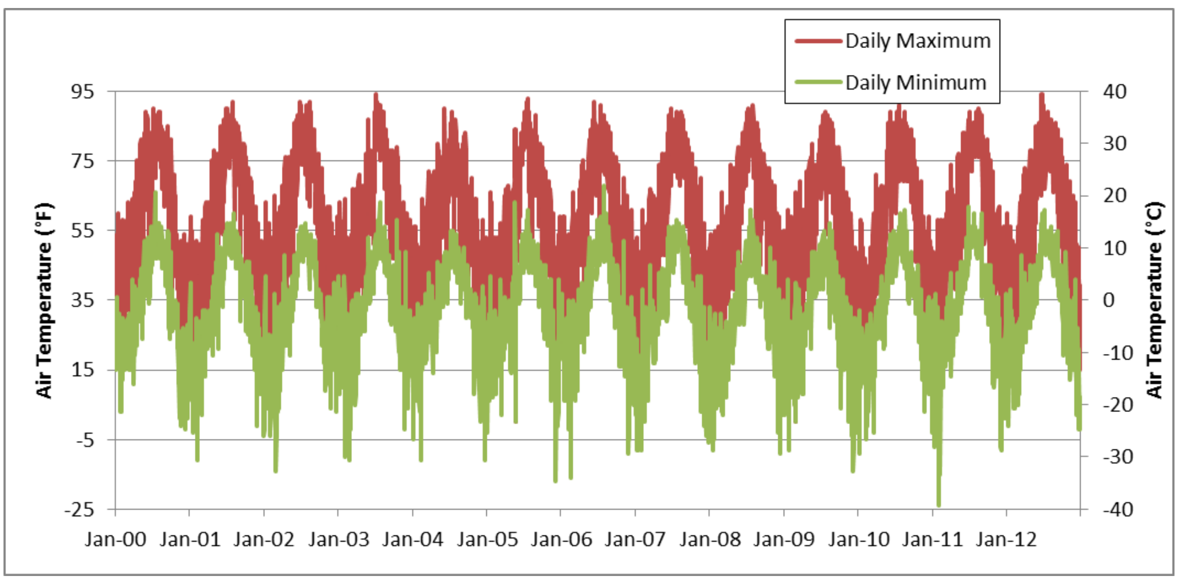

Figure 5. Daily Minimum and Maximum Air Temperature Record from Gross Reservoir Dam, 2000 – 2012

2.2.2.2 Precipitation

Fortunately, daily precipitation data are available at the dam site. Precipitation from 2000 through 2012 averaged 19.6 inches per year at the dam, with a minimum of 14.3 inches (in 2002) and a high of 26.2 inches (in 2004). Seasonal precipitation patterns vary from year to year, but typically the winter months of November through February have the lowest precipitation totals of the year (Figure 6).

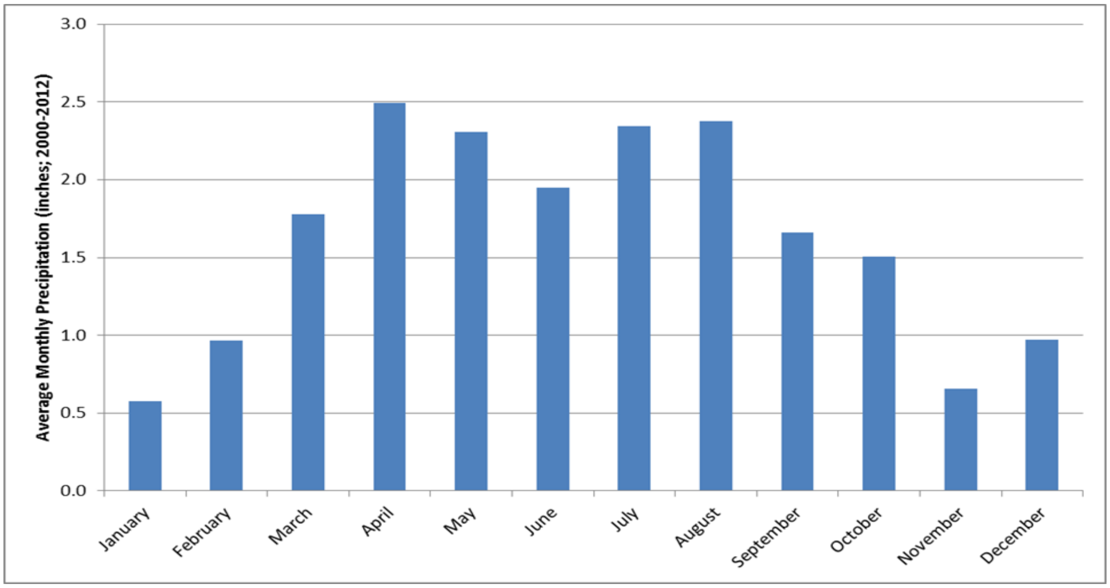

Figure 6. Average Monthly Precipitation Totals at Gross Reservoir Dam (2000 - 2012)

2.2.2.3 Wind

Wind causes turbulence and mixing in a reservoir, which can affect stratification and distribution of materials in the water column. Wind direction is also important, defining the fetch (or length of water over which the wind is blowing). Wind data show that this area can be very windy, and that there is a tendency for stronger winds to come from the east and northeast.

The wind direction data from the Pinecliffe station exhibited distinct periods of non-seasonal directional changes that indicated possible local wind obstructions or anemometer calibration/function errors. Therefore, wind speed and direction data from the Winiger Gulch station were used for the calibration dataset[2]. Most days exhibit gusts of at least 10 mph. Upper range gusts reach 50 mph and higher. Average and maximum daily wind speed follows a generally

[2] Hourly wind speed and direction data were generated by first decomposing the higher-frequency wind vector measurements into east-west and north-south components. Hourly averages of these component vectors were calculated and then combined to generate a resultant vector to determine hourly average wind speed and direction. The east-west components of the wind speeds were consistently greater than the north-south components. Small gaps in the wind data record (~0.9% of all hourly data) were in-filled with the last observed data point.

consistent pattern from year to year, with lower average wind speed observed in summer (Figure 7). The increase in wind speed that typically occurs in October can be a contributing factor in the timing of the fall turnover event.

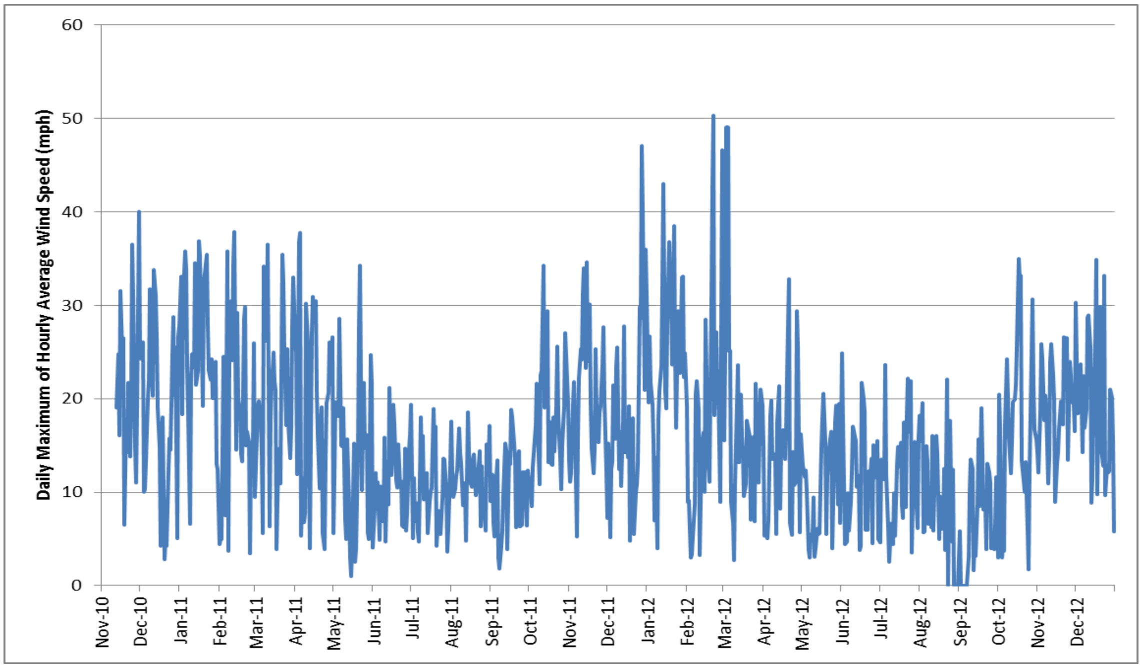

Figure 7. Maximum Hourly Wind Speed Observed at Winiger Gulch Met Station

2.2.2.4 Solar Radiation

Solar radiation is a measure of the radiant energy emitted by the sun. Solar radiation can directly affect water temperature. Each year, solar radiation is greatest in the summer months of June through September. Solar radiation data were obtained from measurements made at the National Wind Technology Center M2 Tower (http://www.nrel.gov/midc/nwtc_m2/). The M2 tower is the nearest location with high-frequency measurements of solar radiation. To adjust for the difference in elevation, the radiation measurements from the M2 tower were uniformly increased by a small amount (0.925%). This adjustment factor was calculated based upon the empirical formula recommended by the American Society of Civil Engineers (Walter, et al., 2002) for determining clear sky solar radiation as a function of incoming extraterrestrial radiation:

$$Clear\ Sky\ Radiation \quad (0.75 \quad 2x10 \quad * \{Ele\ \ ation\ [m]\}) * Extraterrestrial\ Radiation$$

Figure 8 presents the cumulative solar radiation data for each year starting on June 1st and continuing through the end of October. The highest summer cumulative solar radiation was observed in 2010, and the lowest was observed in 2009, but all years show similar patterns and cumulative magnitudes for the summer months.

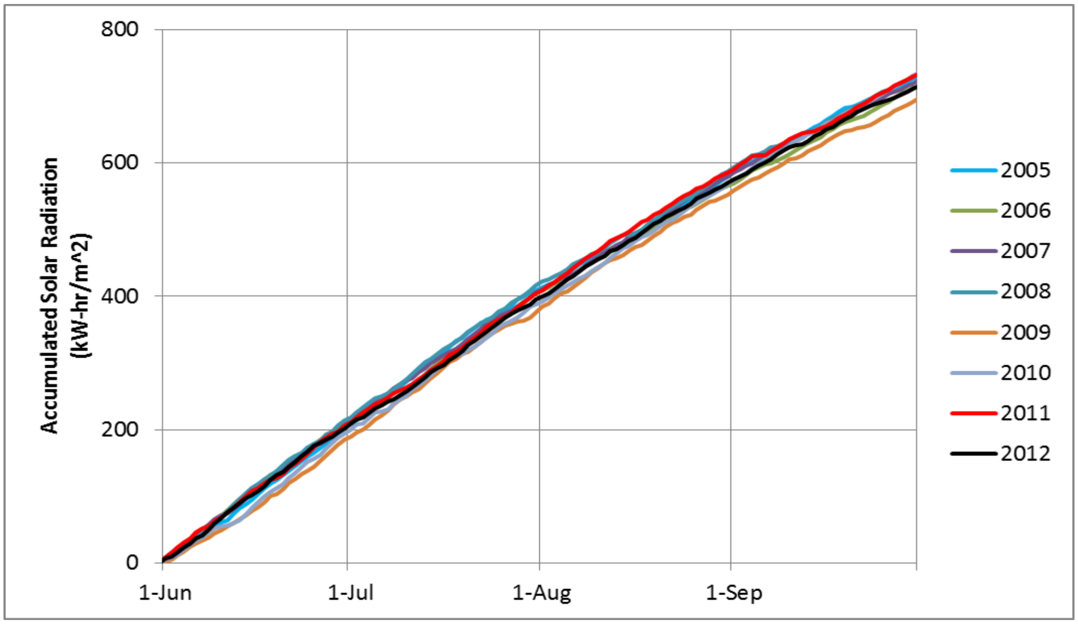

Figure 8. Cumulative Summertime Solar Radiation as Observed at NREL, June through September, 2005-2012

2.2.3 Water Temperature

Available water temperature data from South Boulder Creek, the Moffat Tunnel, and Gross Reservoir were reviewed to provide a conceptual system understanding to serve as a basis for model development. Data were compiled from Denver Water and STORET (which includes data from CDPHE and RiverWatch) for the reach shown in Figure 1. These data represent in-reservoir profile data and South Boulder Creek temperatures upstream and downstream of the reservoir. The focus time period for data compilation was January 2000 through data available as of May, 2013.

On South Boulder Creek upstream of the reservoir, there are two temperature sampling locations. One is immediately upstream of the East Portal of the Moffat Tunnel (WS-RL-018) and the other is less than half a mile downstream of the East Portal (WS-RL-019). These locations are shown on Figure 1. The relatively small temperature dataset available from these locations is presented in Figure 9, along with Moffat Tunnel flow rates and total reservoir inflow rates.

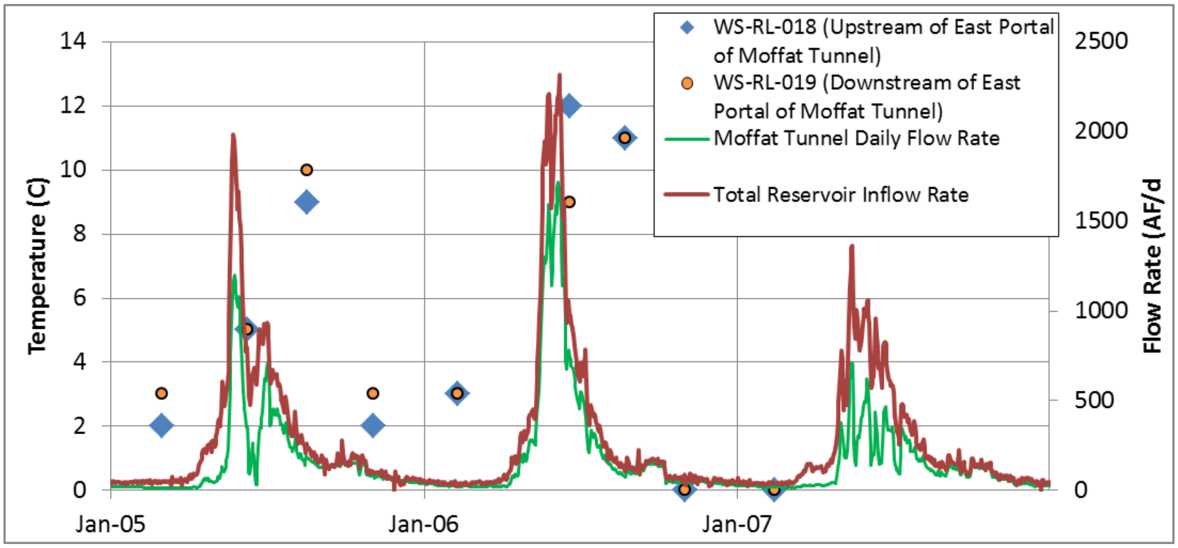

Figure 9. South Boulder Creek Temperature Observations Immediately Upstream and Downstream of the Moffat Tunnel East Portal

The data from these locations are somewhat difficult to interpret, given the limited number of paired data points (9 occasions) and the reporting of results as whole numbers in degrees C. In general, the results show that, with one exception (June, 2006), temperatures at the two locations were within one degree. These limited data do not support an estimation of relative seasonal temperature differences in South Boulder Creek with and without Moffat Tunnel flows. Generally, however, both Moffat Tunnel flows and upstream native South Boulder Creek flows in the spring and early summer largely represent snowmelt runoff, and temperatures would be expected to be fairly similar, as observed in the majority of this dataset.

Figure 10. Photo of Temperature Sensor Location Downstream of Gross Reservoir Dam, Photo Provided Courtesy of Denver Water

Downstream from WS-RL-019 and upstream from the reservoir inlet, there are four temperature sampling locations with data after January 2000. Three of these are data from STORET, and one is from Denver Water (WS-RL-001, shown on Figure 1). The three STORET stations have a limited number of observations (one to 16 observations each), and the most recent data from these locations were collected in 2008. None of these locations is closer to the inlet than the Denver Water location, WS-RL-001, which has 32 observations for the more recent time period of 2009 through 2012. The WS-RL-001 dataset overlaps the continuous temperature data collected at the Gross Reservoir outlet (October 2010 through the present). The continuous outflow temperature data (sensor location shown in Figure 11) are a critical data set for this effort, providing the primary calibration target data.

Based on this, evaluation of inflow temperatures focused on WS-RL-001, located at Pinecliffe. The STORET data locations, with data prior to 2008, were also reviewed, but did not overlap in time with the outflow dataset and are not presented here. Upstream data from WS-RL-001 at Pinecliffe are plotted with continuous temperature observation data[3] from the Gross Reservoir outlet in Figure 11.

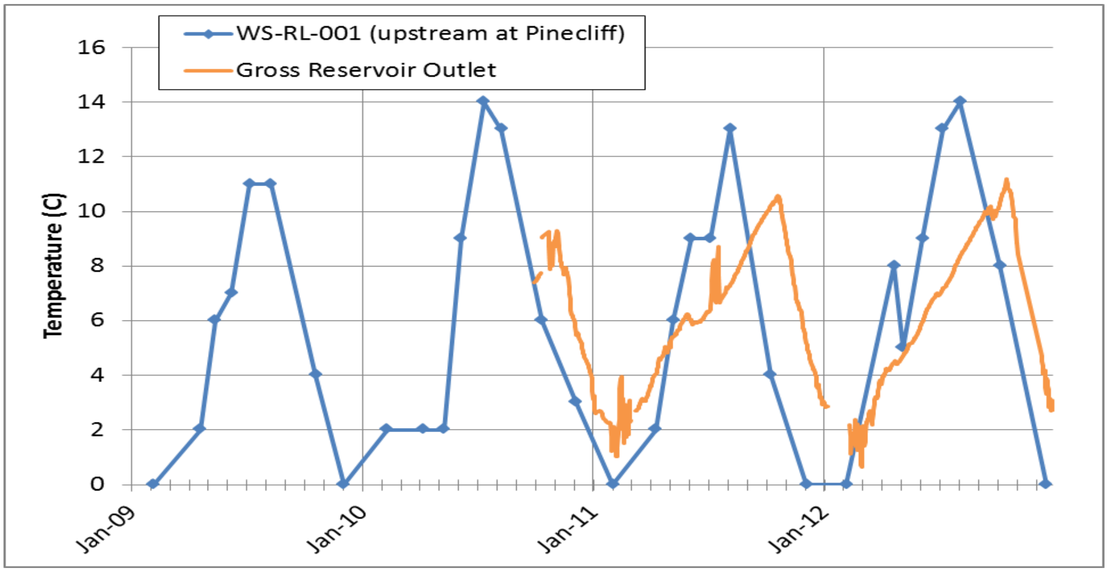

Figure 11. Temperature Data Upstream of the Reservoir at Pinecliffe and Downstream of the Reservoir at the Outlet

Data presented in Figure 11 show temperature differences above and below the reservoir from October 2010 through December 2012. These data show a consistent pattern for the period of record. The reservoir outlet water is cooler than inflow water (as measured at Pinecliffe) from roughly June through August/September. The largest cooling effect observed is 5 to 6˚C in August of 2012. The data show that the reservoir releases water warmer than inflow water for the following months (September/October through early spring.)

It is important to note uncertainty in the WS-RL-001 dataset in interpreting these results. First, WS-RL-001 temperatures are reported to the whole number in degrees C, limiting resolution. Next, further data analysis suggested possible problems with this dataset at times. Specifically, in June of 2011, when Moffat flow rates were very high and comprised the majority of flow in South Boulder Creek at Pinecliffe, temperature from the Moffat Tunnel[4] was measured at 3˚C. At Pinecliffe, temperatures were reported at 9˚C on this same date, implying 6˚C of warming over this reach at a time of very high flow rates (>1,000 AF/d). A warming of 6˚C over this reach

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[3] Note: 1,162 negative temperature points were removed from the continuous outflow temperature dataset prior to calculating daily averages. Data presented in this figure include all positive temperatures measurements.

[4] Temperature measurements were available from the Moffat Tunnel for 2009 through 2012. These did not overlap with data presented on Figure 9, but are shown in entirety in Figure 12.

represents the greatest amount of warming for the period of observed paired records, 2009-2011. Because this also occurred during the highest flow rates from the Moffat Tunnel for the observation period, these data (spring/summer 2011) are considered suspect. These datasets, along with Moffat Tunnel and reservoir inflow rates are presented in Figure 12.

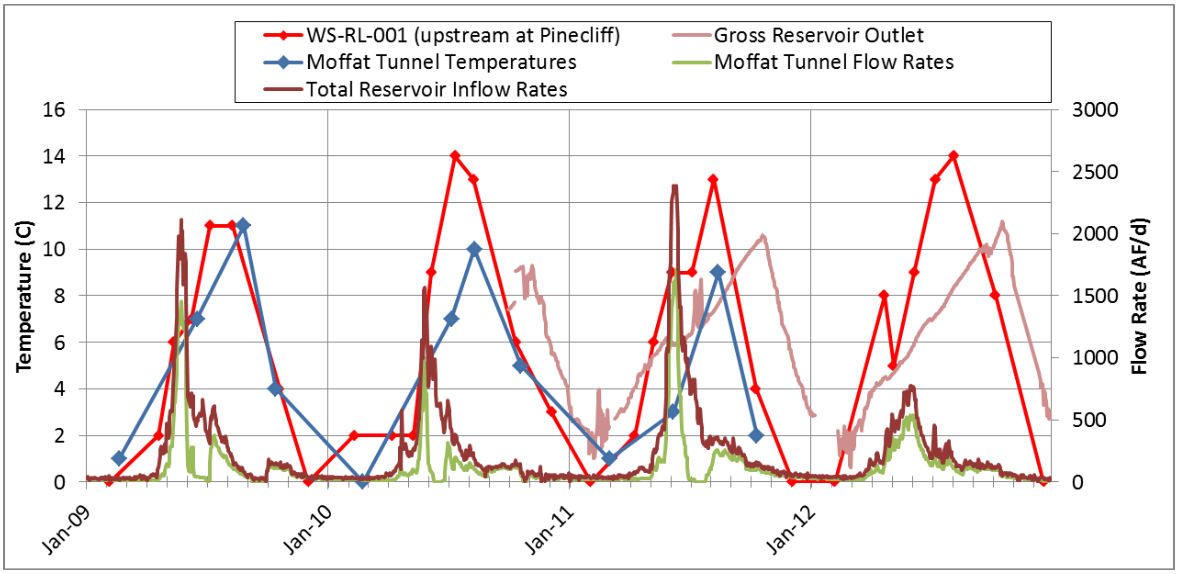


Figure 12. Water Temperature Observations at Moffat Tunnel and Pinecliffe and Flow Rates

Follow up with Denver Water revealed that temperature data from Pinecliffe reflect temperatures taken from water-quality grab samples within a few minutes of collection (Hale, B., email communication to T. Bray, July 17, 2013). This procedure can give reasonable estimates of water temperature, though there could be significant warming of the sample in cases of large differences in air temperature and water temperature, especially as the time between sample collection and measurement increases. Such conditions likely existed in June, 2011. In other years with Moffat Tunnel temperature data, observations were not taken during high tunnel flows, so it is difficult to similarly evaluate other observations. This warming effect could, at times of warmer air temperatures, tend to bias the upstream temperature estimate higher than actual temperatures, resulting in an overestimation of the cooling effect of the reservoir. For this reason, it is difficult to quantify the summer cooling effect empirically, though the general pattern of cooling in summer and warming in winter is expected to be correct.

Based on these data challenges, if there is any anticipated need to continue temperature modeling in the future, it is recommended that continuous, in-situ temperature monitoring devices be installed near the inlet to the reservoir to support future analyses. Ideally, continuous temperature monitoring would also occur at the Moffat Tunnel East Portal and immediately upstream of the East Portal on South Boulder Creek to fully assess temperature effects through observed data.

There is also some uncertainty in the outflow dataset, though this dataset appears overall to be excellent and provides invaluable information for model development and testing. Specifically, the outflow temperature record becomes somewhat erratic during very low flow rates when air temperatures are low (winter months). This is apparent in the early months of both 2011 and 2012, as shown on Figure 12 and Figure 14. This is expected to relate to exposure of the temperature probe to the air at times during very low flows and/or cooling effects within the channel between the dam discharge location and the probe (approximately 500 to 750 ft) during very low flows. To develop the calibration target dataset, observed temperature data from the probe were censored when flows were less than 0.7 Af/d (0.35 cfs) during cold winter months. The result of this censoring is presented in Figure 13, which shows the full set of daily average observed outflow temperatures, the censored data set, and outflow rates from the dam. Note that there is a gap in the data in January of 2012 that was removed not by this low-flow criterion, but instead because these results were negative values. Also apparent on this figure are the managed spill events in July of 2011 which appear as short-duration temperature spikes, reflecting mixing of warmer surface water with the cooler water from the bottom of the reservoir.

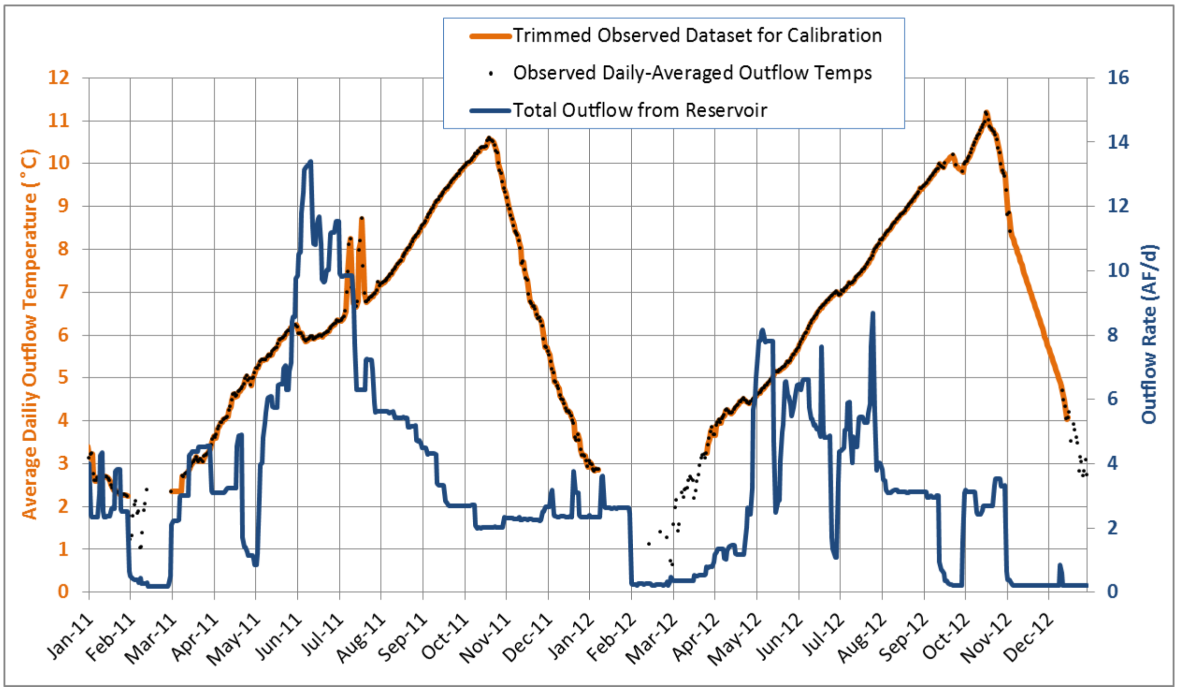


Figure 13. Outflow Water Temperature Data and Outflow Rates, 2011-2012

Within Gross Reservoir, Denver Water collects temperature profiles at two locations, RS-GR-01 (located near the dam) and RS-GR-02 (located near the inlet). These stations are shown on Figure 1. These profiles have been collected three to six times each year since 2007. Temperature profiles have been measured as early as mid-May, and as late as mid-October. These data show that the reservoir thermally stratifies each summer, with top to bottom temperature differences as great as 13.4˚C (observed in July, 2011). Stratification has been observed to start in May, and October profiles typically reflect fall turnover (uniform or nearly uniform temperatures with depth). Additionally, profiles at RS-GR-02 (near the inlet) tend to match profiles to the corresponding depth at RS-GR-01 (near the dam). Profiles also show that the epilimnion (well-mixed top layer) thickness, extending to roughly 3 to 7 m (~10 to 23 ft), tends to be a relatively small portion of the total depth. Further, the epilimnion thickness is much smaller than the typical annual water level variation of up to 20+ m (~66 ft). This was an important factor in model selection. Available profiles data are presented in Figure 14.

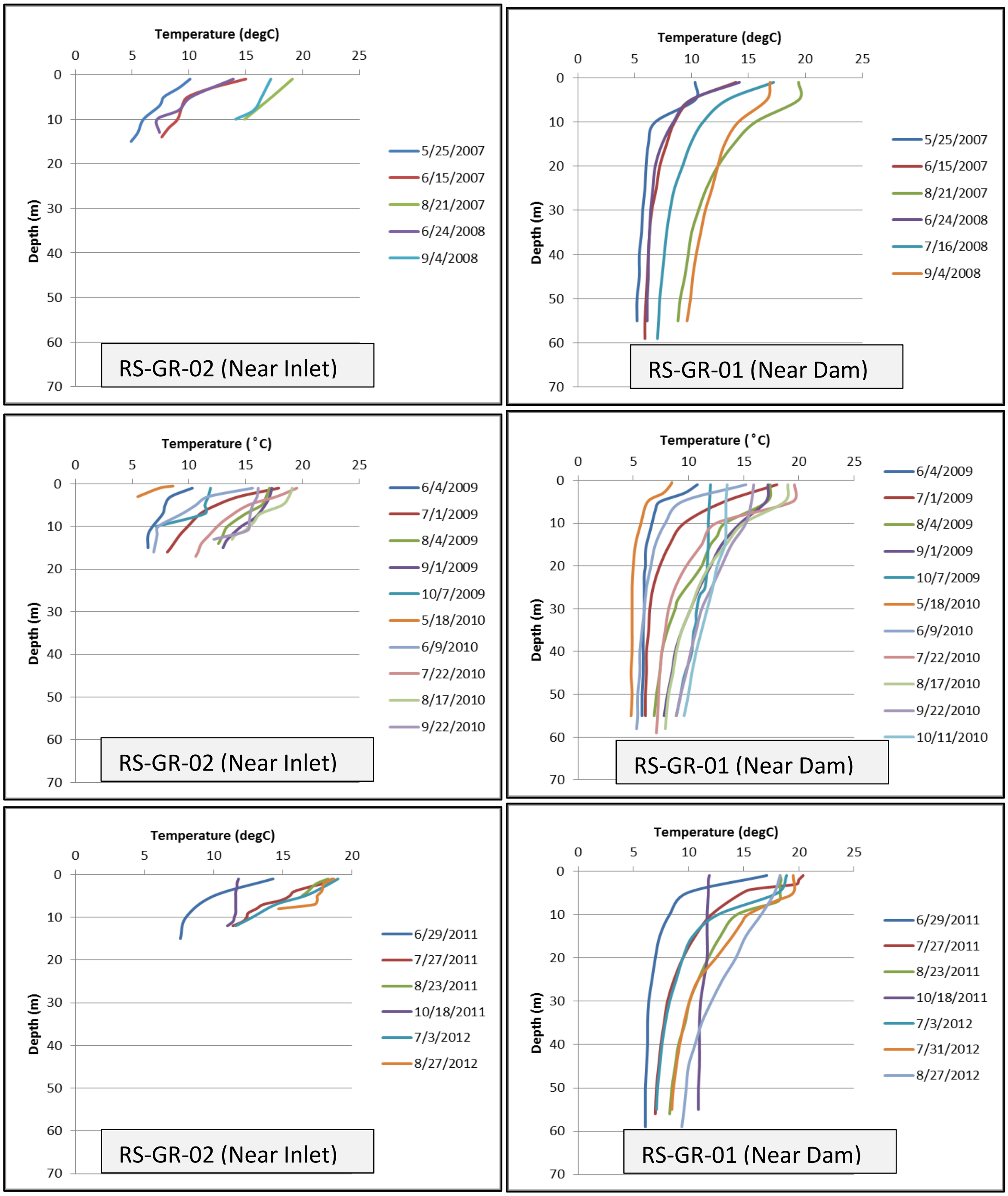


Figure 14. Gross Reservoir Temperature Profile Data from 2007 – 2012

3 MODEL DEVELOPMENT AND CALIBRATION

In this section, the software selected for modeling, development of model input data, and model calibration are described. The model calibration discussion presents of the hydrologic and thermal calibration simulation for the selected calibration time period.

3.1 DESCRIPTION OF MODELING TOOL

To meet project objectives identified in Section 1, the modeling software CE-QUAL-W2 (version 3.6) was chosen to simulate Gross Reservoir. CE-QUAL-W2 is a two-dimensional hydrodynamic and water-quality model. The model assumes lateral homogeneity, but simulates variation longitudinally and vertically to the resolution specified. The U.S. Army Corps of Engineers developed the model, and it is currently supported by Portland State University. The model uses Intel FORTRAN V10.1 to compile, and can be operated from a Windows environment. Detailed documentation of the model and associated technical manuals are available at http://www.ce.pdx.edu/w2/ and in Cole and Wells (2008).

The model was selected for this application for the following key reasons:

- The model is in the public domain.
- The model can simulate ice cover onset, growth and breakup, which could be important for multi-year simulations.
- The model has an excellent reputation and has been applied successfully to more than 450 lakes, including the following reservoirs in Colorado: Horsetooth, Dillon, Aurora, Blue Mesa, Morrow Point, and Crystal.
- The model dynamically[5] simulates vertical and longitudinal water temperatures in the reservoir.
- The model has good, built-in flexibility for outputting data at key locations in the frequency and formats of interest.

In addition to consideration of model capabilities, it is prudent to consider model limitations in selection and application of modeling software. Upon selection of CE-QUAL-W2, the following relevant limitations were noted:

- The model is laterally-averaged, meaning spatial variation perpendicular to the longitudinal axis is not estimated in the simulation.

[5] Simpler dynamic one-dimensional modeling tools, such as Lake2K (Chapra and Martin, 2004), were also considered for this application, but ultimately rejected because of the anticipated importance of hydrodynamics in the reservoir temperature response and the large variation in surface water level relative to observed epilimnion thickness.

- Vertical momentum is not included in the hydrodynamic calculations. The user specifies the vertical turbulence scheme, and eddy coefficients are used to model turbulence. If significant vertical acceleration is occurring in a water body, the model may not be well suited for the application.
- As with all models, this model will be limited by the quality and completeness of input data.

3.2 DEVELOPMENT OF MODEL INPUT DATA

For a hydrodynamic simulation, CE-QUAL-W2 requires inputs for reservoir bathymetry and time series of meteorology, water balance components, and inflow water temperature. Time-series inputs must cover the chosen simulation period. The target calibration period of record was selected based on availability of critical data. The focus of this effort is the simulation of outflow temperatures from the reservoir into South Boulder Creek. For model calibration purposes, having good temperature observations below the reservoir is important, to match model predictions with measurements. Review of the temperature records indicate continuous temperature monitoring at the outlet started in October of 2010, giving two complete calendar years of record (2011 and 2012). Simulation of two consecutive years of record was desirable to simulate winter conditions, since no observed in-reservoir data are available for this season. Therefore, the calibration period was set to be January 2011 through December 2012. Additional reasons for choosing this period include:

- Average water levels and residence times vary widely over these two years, allowing the model to be calibrated to a range of hydrologic conditions. Calendar year 2011 was a wet year with high runoff volumes, and 2012 was a very dry year. Correspondingly, reservoir operations varied. Water surface elevations varied by ~30 m in 2011, but only ~10 m in 2012.
- The period 2011-2012 has nearly complete, proximal meteorological records, which are critical for simulation of observed temperature profiles; and
- The period 2011-2012 has in-reservoir temperature profile data to further support calibration.

Input data development is described below.

3.2.1 Reservoir Bathymetry

The bathymetric representation of Gross Reservoir in the CE-QUAL-W2 model was defined based on three contour maps provided by Denver Water (Portillo, D., email communication to T. Adams, April 2, 2013). The maps were generated during three separate surveys completed by Denver Water in 2001, 2008, and 2012. The information provided included contours for the full expanded reservoir (per Alt1a). The bathymetry was developed for the full expanded reservoir to avoid a step of adding this capacity to the model following calibration.

The maps were compiled and imported into GIS, and a total of 22 cross-section lines were placed throughout the reservoir perpendicular to the direction of flow to generate a two branch bathymetry. The contour data were used to estimate the volumes in each segment at 6 m (~20 ft) intervals between the cross-section lines. This constructed bathymetric representation was then adjusted[6] to match the area-elevation-volume relationship provided by Denver Water (Bray, T., email communication to J.M. Boyer, March 11, 2013).

The resulting model representation of the bathymetry includes two branches. The South Boulder Creek branch consists of 24 active segments. The Forsythe Canyon branch consists of 14 active segments. Segment lengths range between 100 m and 230 m. All segments are oriented according to the azimuth of the thalweg for the segment or group of neighboring segments. Figure 15 presents the plan view of the branches and segments. In this figure, colored segments identify ends of branches and connecting segments.

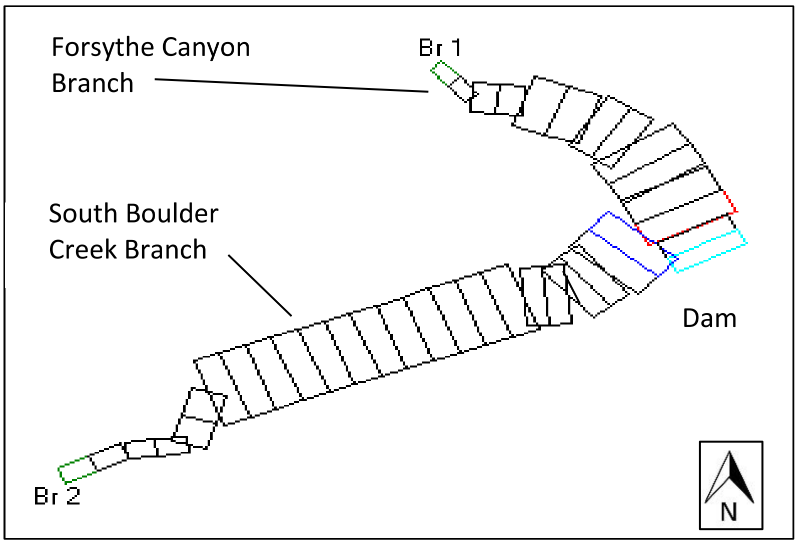
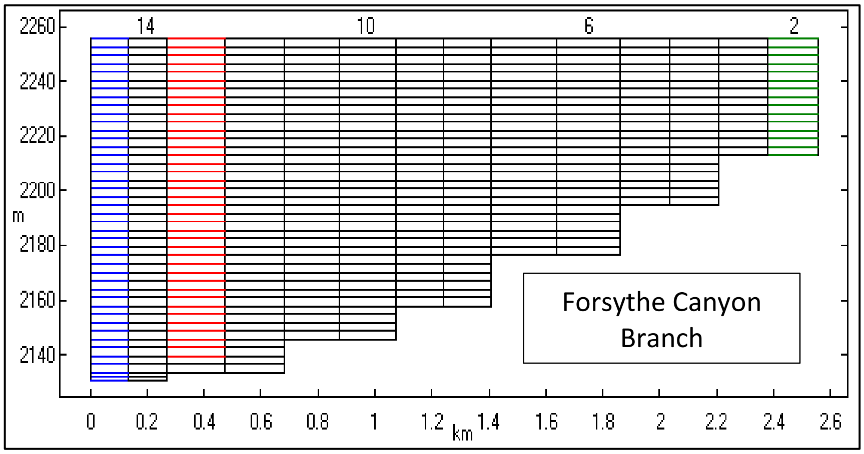


Figure 15. Plan View of Gross Model Branches and Segments

To define the vertical discretization of the model, the 6 m cells were sub-divided to create a vertical resolution of 3 m (~10 ft) for each segment. Vertical resolution was set at 3 m based on best professional judgment, weighing the need to capture critical processes against computational inefficiency of a large number of cells. While the model is capable of managing layer thicknesses that vary vertically, the uniform layer thickness seemed a reasonable approach fit for this system, given the wide-ranging annual water levels and a relatively thin epilimnion layer. Additional resolution was added to the deepest layer at the dam, with a 1.5 m vertical discretization, to support predictions of outflow temperatures. Figure 16 presents the vertical cell discretization for each branch of the model. Note in this figure that the direction of flow is from right to left, which is the opposite of that presented in Figure 15. As in Figure 15, green outlined cells and blue outlined cells indicate upstream and downstream segments, respectively. The red outlined cells indicate the location of the inflow connection from the South Boulder Creek branch.

[6] Uniform adjustments of widths were made at each layer in order to achieve a match with the elevation-volume relationship provided by Denver Water.



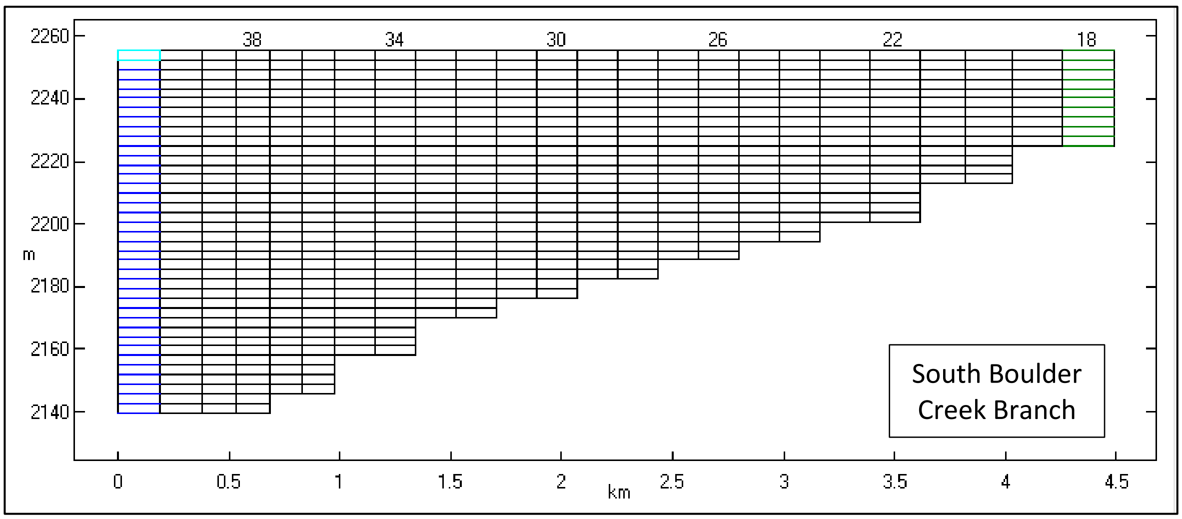


Figure 16. Profile Views of Gross Reservoir Model Branches

In addition to specification of the segment lengths and thicknesses, the width of each segment was specified to generate the appropriate volume at each depth (as described above). Figure 17 shows example views of width designations, looking at cross-section views in the direction of flow.

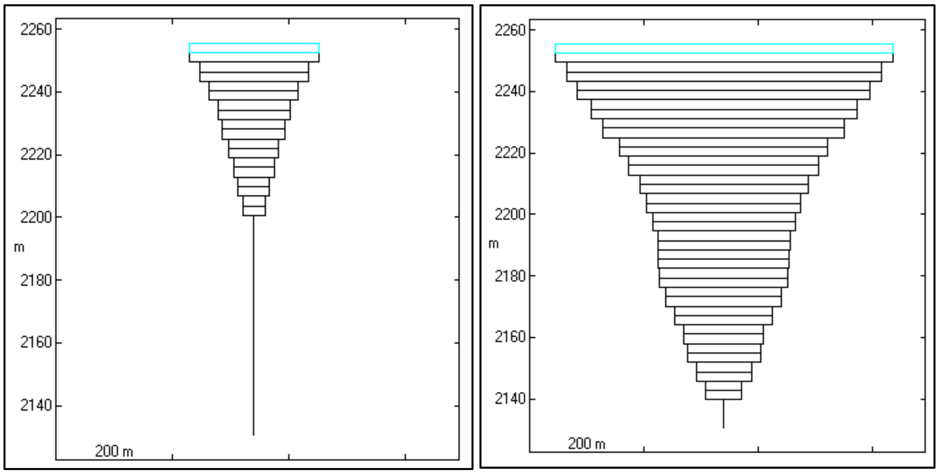


Figure 17. Example Cross-Section Views of South Boulder Creek Branch Segments of the Gross Model

Elevation-to-volume relationships were developed from the model cells by adding up cell volumes at each 3 m cell depth interval over the entire model. As discussed above, the segment widths were adjusted to match the volume-elevation relationship provided by Denver Water, to support implementation of the water balance (Figure 18).

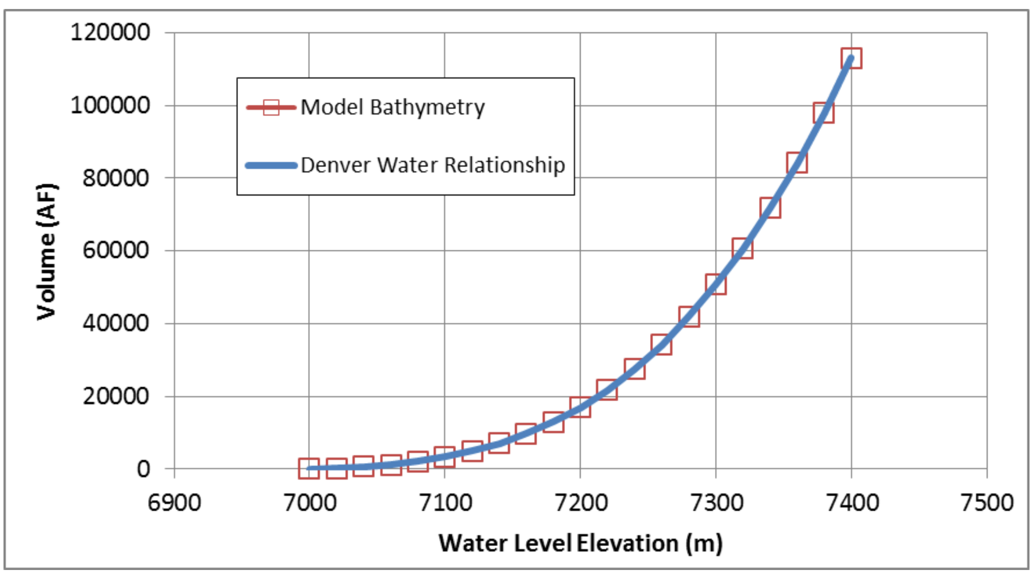


Figure 18. Gross Reservoir Model Volume-Elevation Compared to Denver Water's Estimated Relationship

The model surface area is compared to Denver Water's estimated surface-area-to-elevation relationship in Figure 19. Within the current and proposed enlargement operating range of water elevations, the model and Denver Water estimated relationship are within 6%.

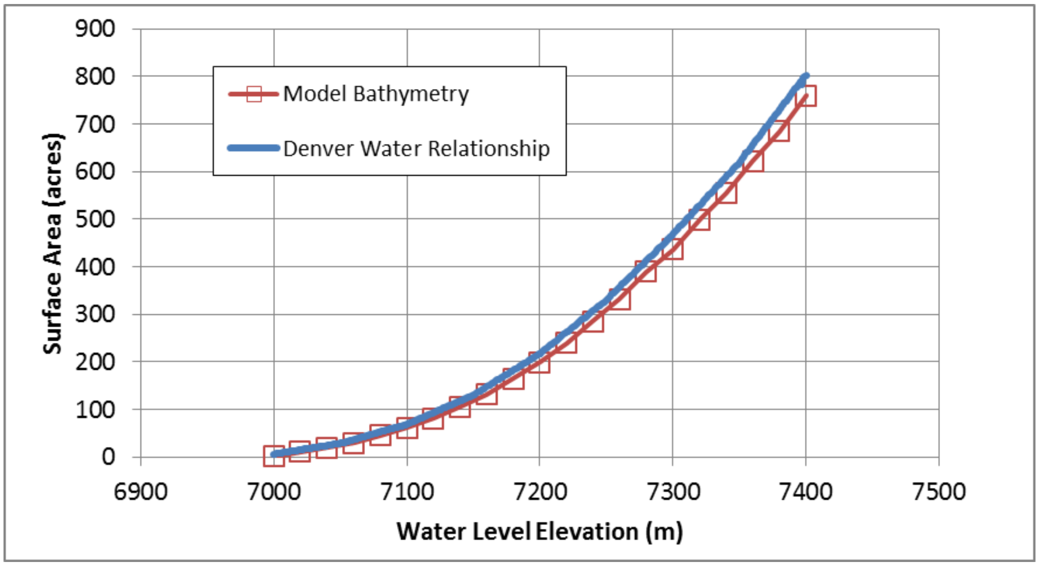


Figure 19. Gross Reservoir Model Surface Area-Elevation Compared to Denver Water's Estimated Relationship

Following bathymetry development, outlet works were placed in the model at the location of the Gross Reservoir Dam outlet works. The outlet was set up to use the selective withdrawal algorithm in the CE-QUAL-W2 code. This algorithm calculates a time-varying withdrawal zone for the outlet based on outflow, outlet geometry, and upstream density gradients. Figure 20 shows the location of the outlet works on the Forsythe Canyon branch in the model (elevation 2,131 m [6,993 ft]). As in Figure 16, this figure is oriented such that flow is from right to left (blue arrow). An additional withdrawal location was specified from the top of the reservoir at the spillway (elevation 2,220 m [7,282 ft]) for simulation of the spill events that occurred during July of 2011. This is close to the current dam crest elevation of ~2,222 m.

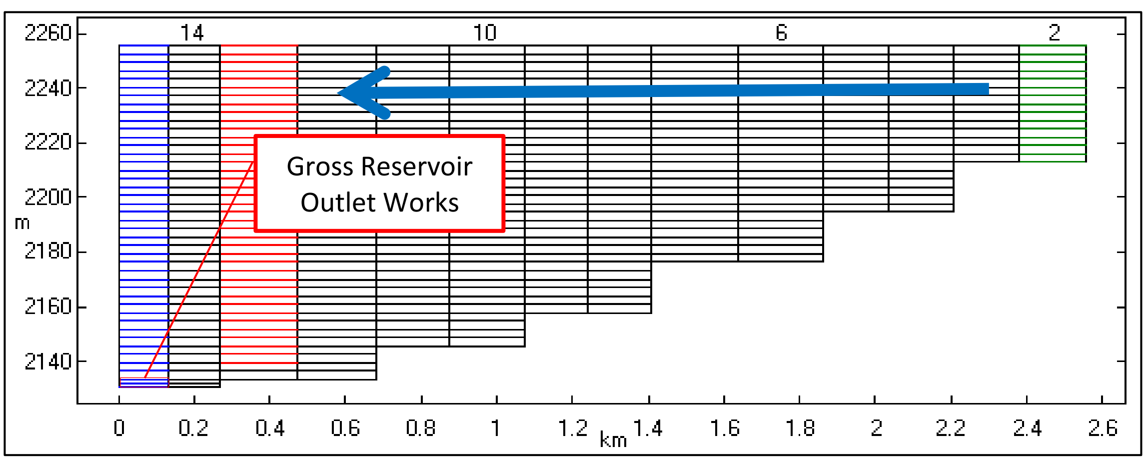


Figure 20. Outlet Works in Gross Reservoir Model

3.2.2 Meteorology

Meteorological data for air temperature, precipitation, solar radiation, wind, and cloud cover are required by the model. Discussions of the available data and the compilation of those data for use in the model are described in Sections 2.2.2.1 through 2.2.2.4. Data for the 2011-2012 calibration period were processed for input into the model.

3.2.3 Reservoir Water Balance

As presented in Section 2.2.1, a water balance for the calibration period (January 2011 through December 2012) was developed from the following information provided by Denver Water:

- Daily reservoir water levels (converted to reservoir storage volumes);
- Daily outflow rates from the outlet works at the dam;
- Monthly evaporation rate estimates (depth/day); and
- Daily precipitation rates (depth/day, converted to volumes using daily reservoir surface areas).

Precipitation and evaporation comprised 0.6%, and 0.9% of the average annual storage volume for this period of record, respectively. Inflows were calculated as the closure term in the water balance.

The daily water balance was used to develop model inputs. Evaporation values were input as distributed terms over active segments. All inflows were assumed to enter at South Boulder Creek. This simplifying assumption was made recognizing that some of the total inflow enters via the Forsythe Canyon branch and in the middle of the South Boulder Creek Branch via Winiger Gulch; however, there were no available estimates to support a percentage breakdown and no available temperature measurements for these inflows. The assumption is considered a reasonable approximation given that the vast majority of inflows enter the reservoir via South Boulder Creek. This is by far the larger portion of the natural drainage and includes Moffat Tunnel flows, which comprised 59% of inflows in 2011 and 2012.

In 2011, there were two spills from the top of the reservoir in response to the high inflow volumes. Both covered roughly six days and occurred in July. Spill volumes were uncertain but estimated to be a total of ~130 AF, comprising approximately 10% of total discharge during that period of time. The estimated volumes were input into a withdrawal from the top of the reservoir during these days.

3.2.4 Inflow Temperature

The best available inflow water temperature estimates for the two-year calibration period were 16 measurements of water temperature collected ~2.6 river miles upstream of the Reservoir at Pinecliffe (see Figure 1). Unfortunately, these data points are reported as whole values in degrees Celsius, limiting resolution. Further, of these data points, a total of only seven were collected during the spring runoff hydrograph during the two years, providing little information about the temperature of the majority of inflow volumes. Additionally, as described in Section 2.2.3, these temperature data are considered suspect as representative of in-river temperatures, particularly in the spring of 2011, based on comparison to Moffat Tunnel observations[7]. Further, the reported practice of measuring water temperatures in sample bottles within a few minutes of collection, rather than directly measuring in-stream temperature (Hale, B., email communication to T. Bray, Jul 17, 2013) is a significant source of uncertainty with respect to the representativeness of these data. Based on all of this, inflow water temperatures were treated as a calibration variable, with a goal of developing a consistent way to estimate inflow water temperatures for runs simulating EIS alternatives.

Attempts were made to correlate Pinecliffe temperature data to flow rates and air temperatures by season and to break out the relative thermal contribution of Moffat Tunnel flows by percent volume and season. Unfortunately, consistent patterns were not uncovered with the limited dataset available. Recognizing that the Pinecliffe data represent the best available estimates of inflow temperatures, these values were input directly into the model, using a simple linear fill to assign temperatures between observation dates. These were starting point inputs. As noted above and discussed below (in Section 3.3.2), due to the uncertainty in these values, inflow temperature were adjusted as part of calibration.

3.3 CALIBRATION

This section presents calibration of the Gross Reservoir Model. Calibration is the process in which model coefficients are adjusted to produce a reasonable match between observed and simulated results. The process is iterative and not prescriptive. Calibration was achieved by adjusting mechanistically- and conceptually-relevant coefficients within reasonable ranges. Reasonable ranges of coefficient settings were defined by model guidance documents and literature. The calibration was completed in two main steps. First, the hydrology was simulated and compared to observations. Next, water temperatures were calibrated, focusing primarily on reservoir outflow temperature but also assessing in-reservoir profile data.

The following subsections present the calibration approach and results for hydrology and temperature.

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[7] As discussed in Section 2.2.3, water temperature data from Pinecliffe reflect measurement of water sample temperatures, which can be measured several minutes after collection from the river. As a result, this can produce an erroneous estimate of in-river temperature, particularly if there is a large difference in air and water temperature. Such conditions likely occurred in May, June, and July of 2011 when 500 to 2,300 AF/day of snowmelt runoff was flowing in South Boulder Creek below Moffat Tunnel. Comparison of a Moffat Tunnel temperature measurement in June, 2011 with a Pinecliffe observation from the same day showed six degrees of warming between the Tunnel and Pinecliffe, which is the greatest amount of warming on record. Record warming between the Moffat Tunnel and Pinecliffe would not be expected at that time given the estimated 2,300 AF/day flowing in South Boulder Creek at Pinecliffe on the day of the observations.

3.3.1 Hydrology

The results of the hydrology simulation were compared to daily water surface elevation values from the Denver Water records (Figure 21). The average daily error for the model simulation relative to the observed water levels was -0.06 m, and the mean absolute error was 0.13 m, ranging from a maximum positive daily residual of +0.2 m to a maximum negative daily residual of -0.9 m (June, 2011).

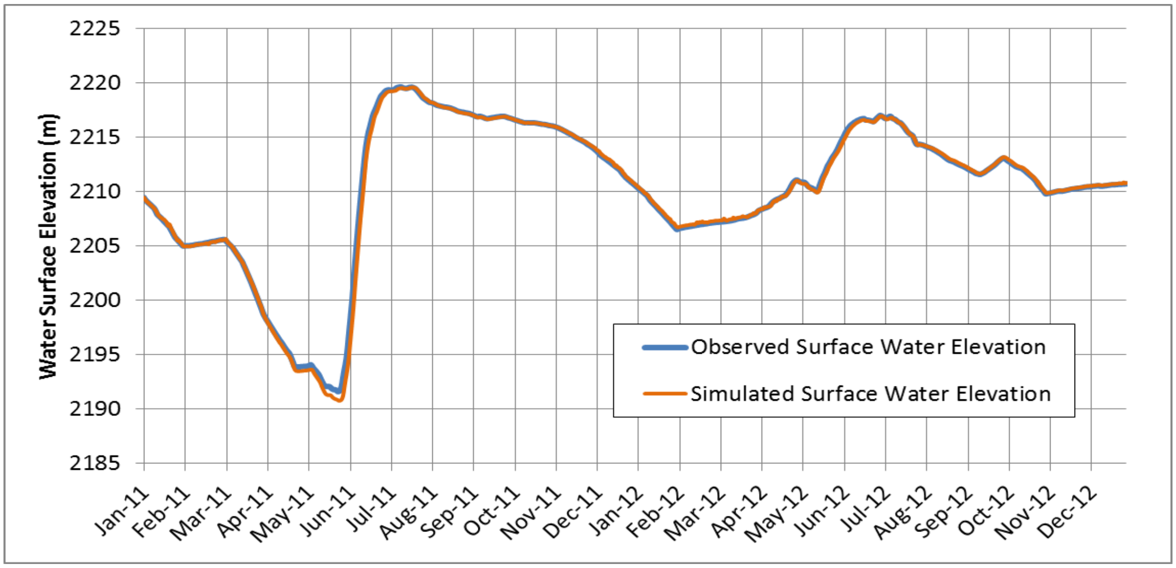

Figure 21. Hydrology Calibration Simulation – Daily Water Surface Elevation

3.3.2 Water Temperature

As discussed in Section 2.2.3, Gross Reservoir stratifies strongly each year, turning over in the fall. Water temperature is simulated as part of the hydrodynamic simulation in CE-QUAL-W2 because of its effect on water density. The following subsections present the approach to and results of the calibration of water temperature.

3.3.2.1 Approach and Challenges

Calibration of water temperature focused primarily on adjustment of key coefficients and comparison of output to continuous temperature records of outflow collected below the dam. Available in-reservoir profile data for the calibration period were also evaluated against simulation results. Conceptually, it is recognized that thermal response in a large reservoir in this region is typically determined by the following major controls:

- Air temperatures,
- Wind,
- Solar radiation (long and short wave),
- Inflow water temperatures,

- Hydrodynamics (bathymetry, discharge location, discharge rates), and
- Ice cover (onset, solar radiation reflectance properties, and melting).

Within the model, there are a variety of settings and coefficients that affect the simulated response of water temperature. The key temperature-related coefficients in CE-QUAL-W2 are:

- Hydrodynamic settings
    - Longitudinal eddy viscosity
    - Longitudinal eddy diffusivity
    - Bottom roughness
- Meteorological-related settings
    - Wind sheltering
    - Shading
- Heat exchange settings
    - Air-water/evaporation
    - Water-sediment
- Water absorption/reflection settings
    - Absorption of solar radiation in surface layer
    - Extinction coefficients (pure water, organic solids, inorganic solids).
- Ice Cover Settings
    - Ice formation
    - Albedo of ice

For this model of Gross Reservoir, a subset of key terms and setting were the most sensitive and critical for calibration of water temperatures. First, assumed initial in-reservoir water temperatures were developed through calibration. The model simulation was somewhat sensitive to this setting, particularly during the first year of simulation. Vertical profiles of water temperatures in the reservoir were not available near the start date of January 1, 2011; therefore, calibration of values was required. Both vertically-varying and constant temperature profiles were tested as starting conditions. Values were generated based on simulation results from January 1, 2012 and December 31, 2012. Ultimately, the calibration applied a uniform temperature initial condition of 3.5 °C with no ice cover on January 1, 2011.

Ice cover parameters were also sensitive in the calibration, affecting outflow water temperatures particularly from early spring through early summer months due to their influence on reservoir heating during winter and early spring. Ice cover parameters in the model were adjusted primarily based on their effect on the simulated outflow temperatures and early-season water temperature profiles. For the calibrated model, ice albedo was adjusted from a default 0.25 to 0.1. Ice albedo values on the order of 0.1 have been reported for clear lake ice (Bolsenga, 1969). Other ice-cover parameters were set to default values.

The greatest uncertainty in calibration of water temperature was the time series input of inflow water temperatures. When inflow rates are high, the simulation of in-reservoir water temperatures was very sensitive to inflow temperatures. The model was run with the "density placed inflow" function turned on to allow for distribution of inflows according to density (which is primarily a function of temperature for this system). Inflow temperatures strongly affect the heat loading to the reservoir, but also impact mixing patterns.

Using the inflow temperatures described in Section 3.2.4, reasonable results were achieved for early 2011 and all of 2012, when inflow rates were relatively low. For spring and summer of 2011, however, when inflow rates to the reservoir were high, the Pinecliffe temperatures did not produce good results, even with reasonable adjustment of all available thermal calibration parameters.

To allow for model calibration, thermal calibration parameters other than those described above were reset to default values, and inflow temperatures during the snowmelt runoff hydrograph in 2011 were adjusted until reasonable simulation results were achieved. The adjustment was done uniformly and targeted values warmer than Moffat Tunnel observations but cooler than Pinecliffe recorded values at the time. This process produced an assignment of inflow water temperatures of 4.75˚C during times when spring inflows to the reservoir exceed 500 cfs (992 AF/d). This adjustment of Pinecliffe water temperatures only affected 2011, since flows did not reach the threshold in 2012. More complicated adjustments of inflow temperatures could produce even better simulation results; however, this simpler adjustment was selected to allow for comparable application of assumptions to simulation of EIS alternatives (discussed in Section 4). The simulated inflow temperatures are plotted in Figure 22, along with the data points from Pinecliffe and the Moffat Tunnel, as well as inflow rates to the reservoir.

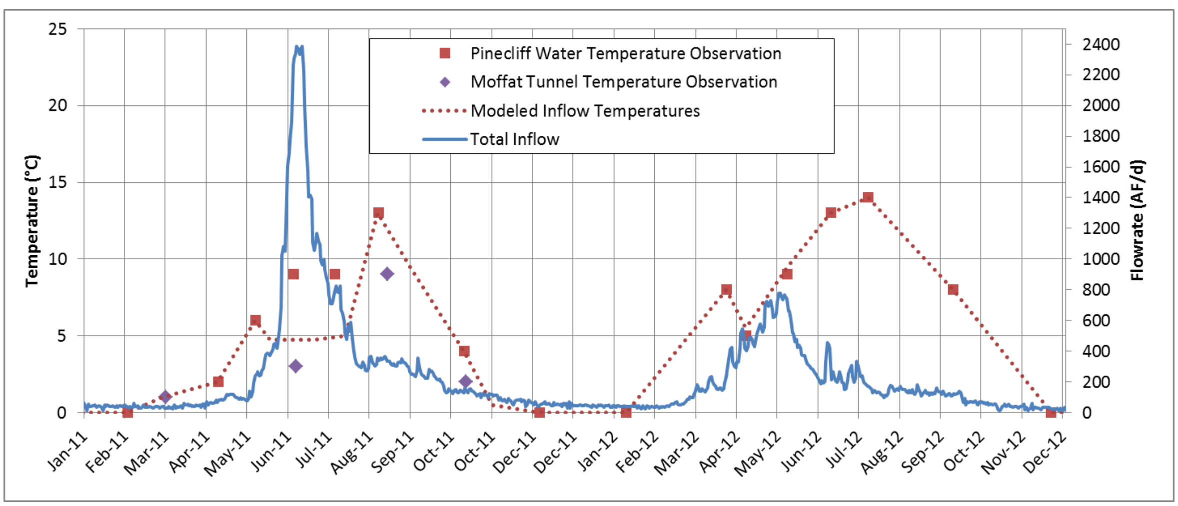

Figure 22. Calibrated Inflow Water Temperatures, Pinecliffe Observations, and Reservoir Inflow Rates

Other adjustable model coefficients/inputs, including hydrodynamic coefficients, wind sheltering, and shading, exhibited sensitivity in the model but were ultimately set to default values. While adjustment of these parameters improved simulated response for portions of the modeling period there were negative effects at other times, and there was no basis for applying temporally and/or spatially varying settings of these parameters.

3.3.2.2 Results

In spite of the uncertainties and calibration challenges discussed above, the water temperature calibration for the reservoir outflow temperatures is considered very good. First, the model simulates formation and breakdown of stratification from year to year. Figure 23 shows model output for the two year calibration simulation at the RS-GR-01 location, near the dam. This figure shows a compilation of color profiles for each day of the simulation, and also includes representation of the changing water level.

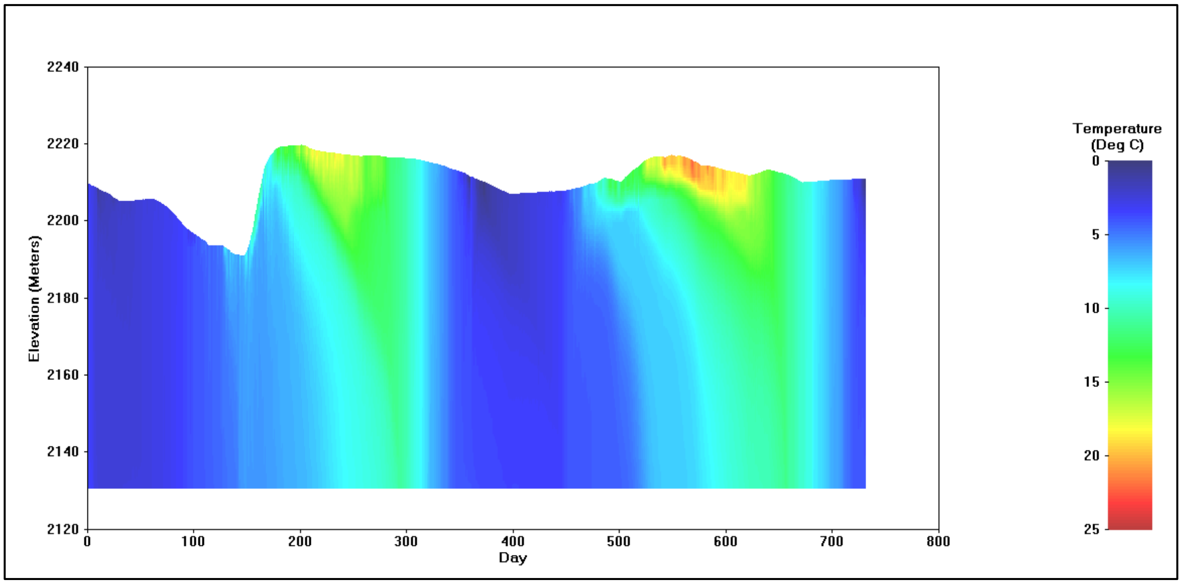

Figure 23. Calibration Period (January 1, 2011 through December 31, 2012) Thermal Simulation at RS-GR-01 (Near Dam), 2011 through 2012

The primary calibration target was the continuous water temperature record collected by Denver Water below the Gross Reservoir dam. Outflow temperatures from the calibrated model are plotted against the observed outflow temperatures in Figure 24. The model performs well in both 2011 and 2012, capturing the seasonal pattern of warming and cooling of outflow temperature, including peak temperatures and timing of the peaks. In June of 2011, two spikes in outflow water temperature were observed. These correspond to spills from the reservoir, where warmer water from the top of the reservoir was released with the bottom releases as part of the reservoir management operation during this very wet year. The model simulated the general effects of the spills. While the temperatures of the peaks were underestimated, this is expected to largely reflect uncertainty in the spill volume.

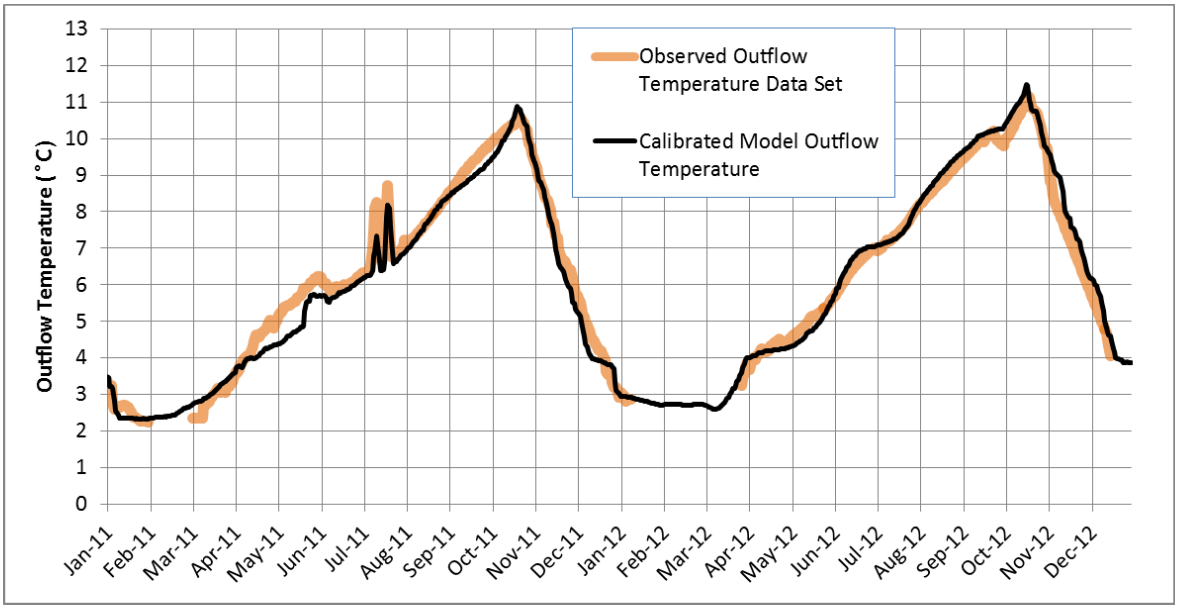

Figure 24. Observed and Simulated Outflow Water Temperatures, 2011 through 2012

In additional to a good visual match of observed data, the model results for outflow temperatures produced low error summary statistic values. The absolute mean error (AME) for daily temperatures of Gross Reservoir releases for the full calibration period (2011 through 2012) was 0.2˚C, and the root mean squared error (RMSE) was 0.4˚C.

As a further check on model calibration, modeled temperature profiles were compared to observed temperature profiles in the reservoir for the period of record. The model performed well simulating the temperature profiles near the inlet and near the dam during both year of simulation. Figure 25 and Figure 26 present results from 2011. Figure 27 and Figure 28 present results from 2012. Note that the shallowest point on each profile of simulated results represents an average of up to the top 3 m of the reservoir (cell thickness), whereas the observed dataset typically has an observation starting at a depth of 1 m, so the upper-most data points in observed and simulated profiles are not directly comparable. The ability of the model to capture early season temperatures and stratification, including the thickness of the epilimnion, is encouraging that the water temperatures throughout the reservoir are well simulated. Differences in profile shape seen in August of 2011 are expected to reflect wind input uncertainties and do not seem to cause problems with the outflow temperature simulation. The AME values for the profiles average 0.6˚C, ranging from 0.2˚C to 1.3˚C, and the RMSE values average 0.9˚C, ranging from 0.3˚C to 1.6˚C[8]. Given the wide range of conditions in these two consecutive calibration years (wide range of inflow volumes and water level patterns), the consistently good simulation of water temperatures offers a high degree of confidence in simulation results.

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[8] Because model output is limited to the resolution of the vertical layers (3 m) and observation data do not match these depths, interpolation was a necessary preprocessing step before AME or RMSE could be calculated. Linear interpolation was used to match up simulated and observed temperature profile depth values.

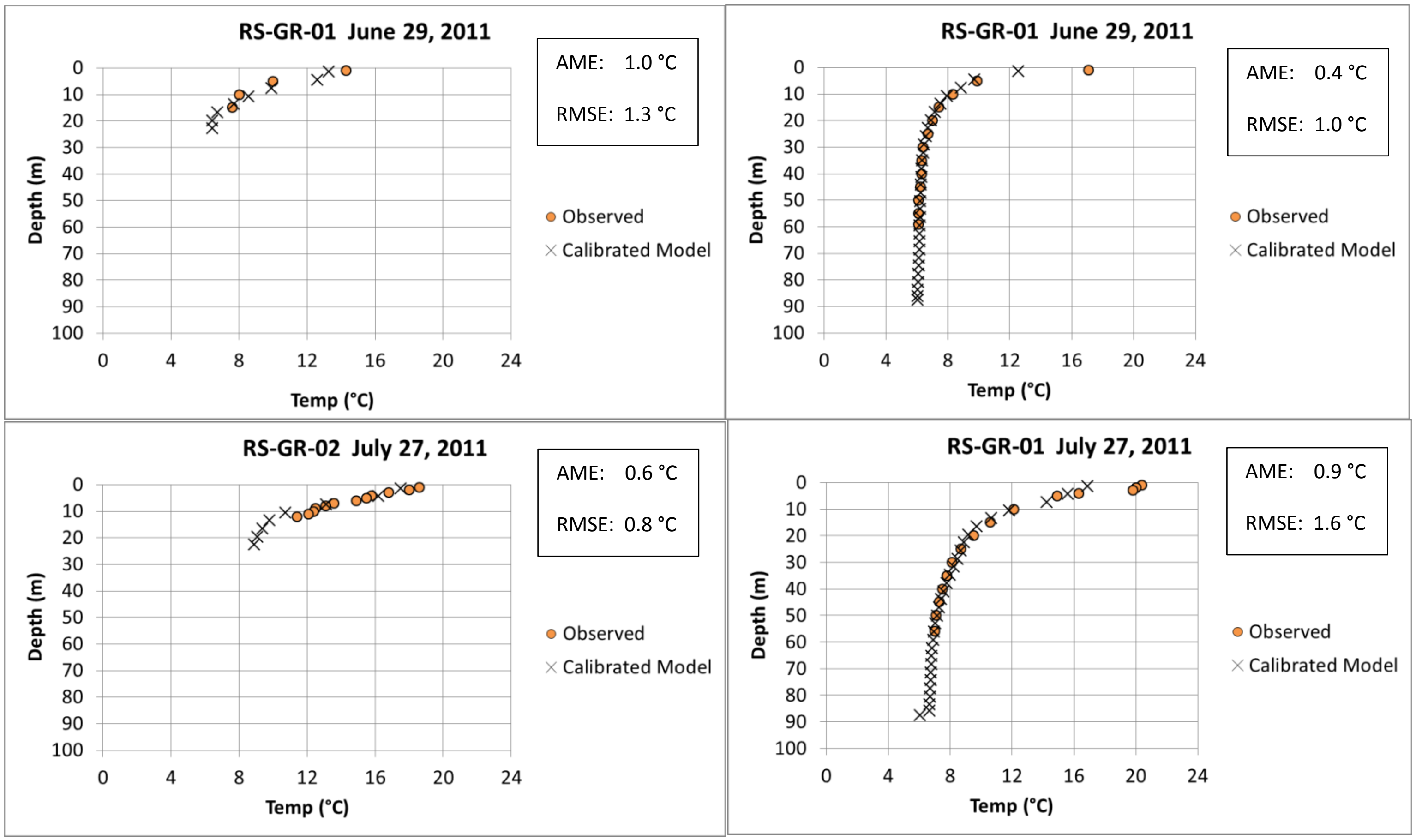

Figure 25. Comparison of Observed and Simulated Temperature Profiles in June and July of 2011

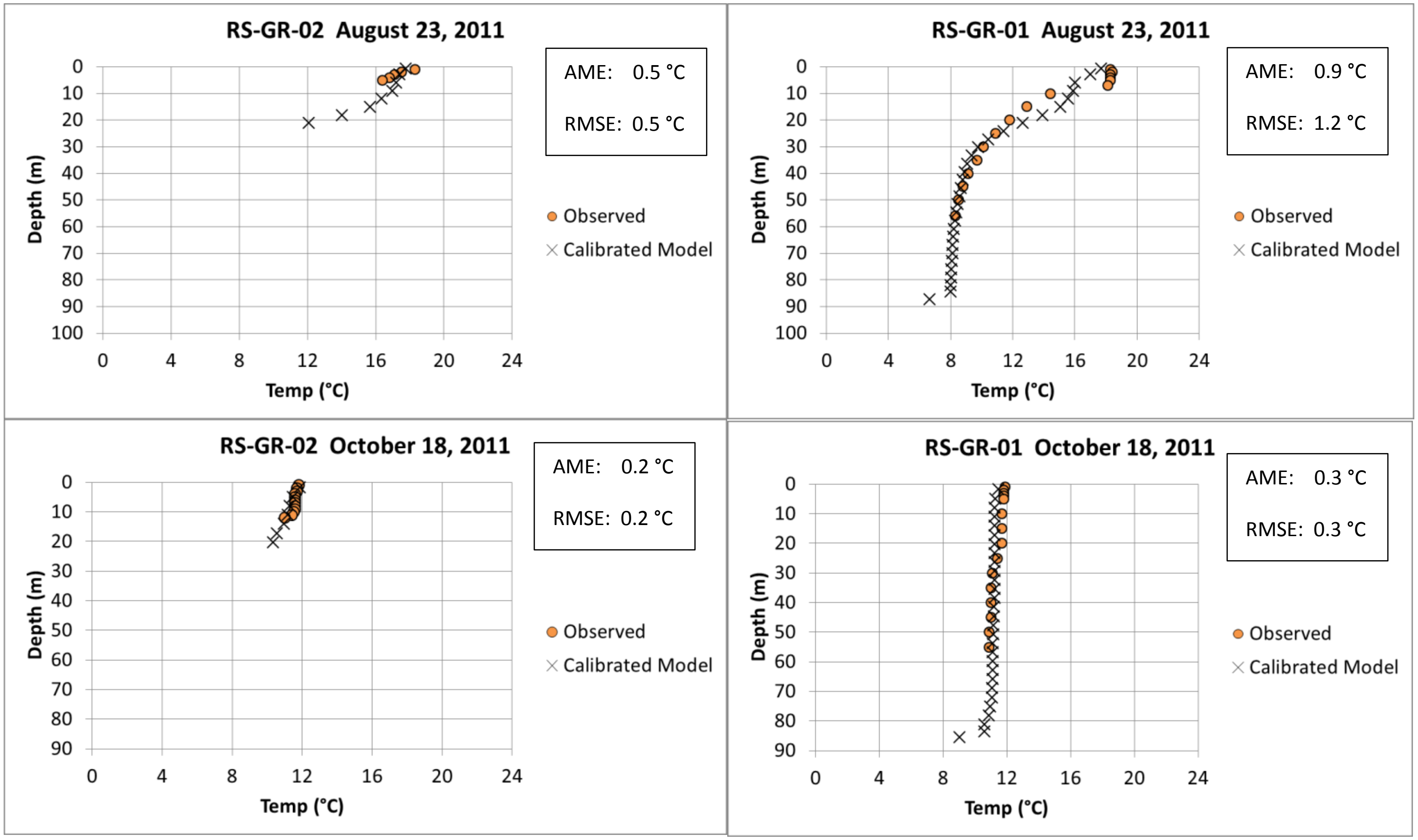

Figure 26. Comparison of Observed and Simulated Temperature Profiles in August and October of 2011

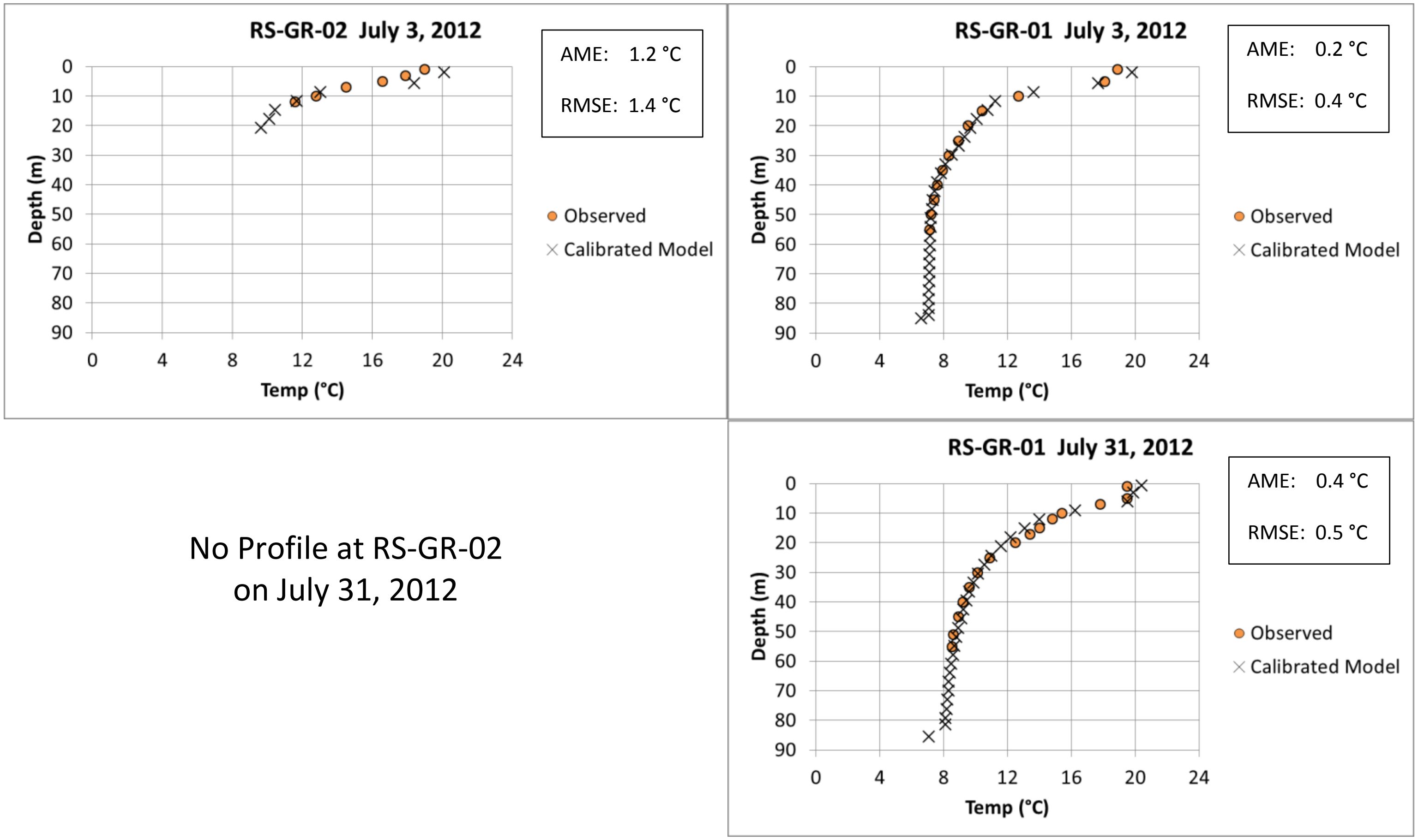

Figure 27. Comparison of Observed and Simulated Temperature Profiles in July of 2012

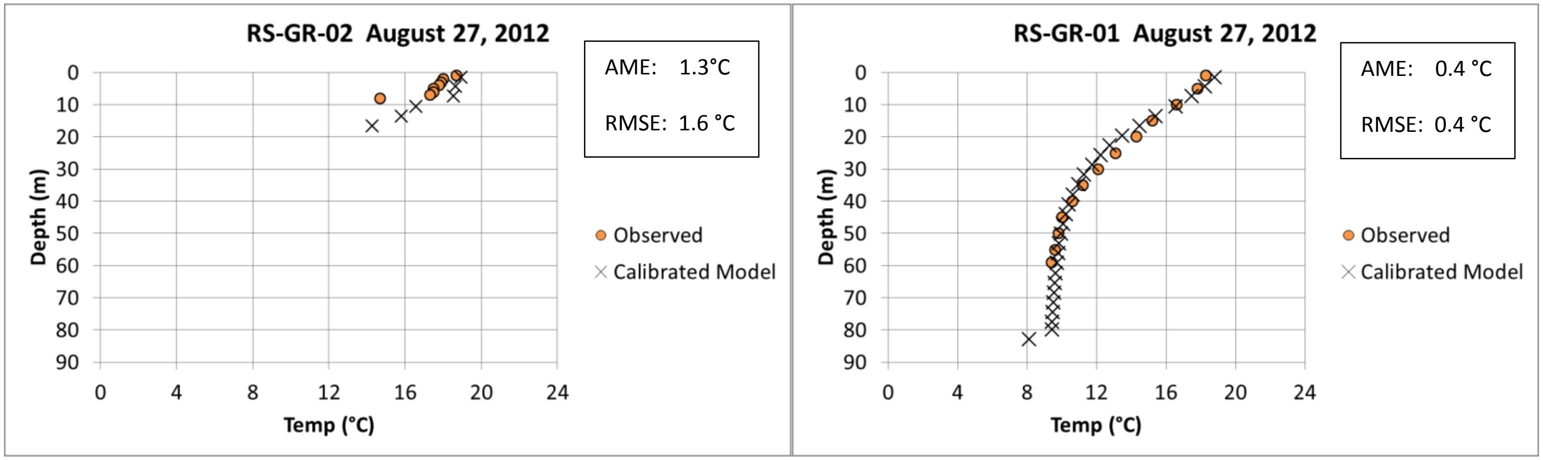

Figure 28. Comparison of Observed and Simulated Temperature Profiles in August of 2012

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4 MODEL APPLICATION

The calibrated model was applied to simulate the outflow temperatures for the proposed expansion of Gross Reservoir for the Proposed Alternative (Alt1a) in the PFEIS (USACE, 2012). The expansion of the reservoir involves increasing the height of the dam by 38 m (125 ft), roughly tripling the storage volume and doubling the surface area. The water-quality concern prompting model development and application is that expansion of the reservoir could lead to colder release temperatures, resulting in aquatic-life concerns in South Boulder Creek below the dam.

The following subsections present the approach and results of simulating the effects of the expansion on outflow temperatures with the calibrated, two-dimensional, dynamic model of the reservoir. Results are presented and summarized.

4.1 APPROACH TO SIMULATE OUTFLOW TEMPERATURES FOR EXPANDED RESERVOIR (ALT1A)

To assess the effects of reservoir expansion and operational changes on outlet water temperatures, an approach to define model runs was developed. The goal of the effort was to generate model-simulated outflow temperature data that would support an assessment of the potential temperature impacts of the proposed alternative (Alt1a) on downstream aquatic life. Since running a large suite of combinations of alternatives, hydrologic years, assumed meteorological inputs, and inflow temperatures was not practical, decisions were made to develop a narrow set of runs that could produce results that would attempt to “bracket” the potential difference in outflow temperatures (Hydros, 2013). The approach taken to develop this list of model runs is discussed in the following subsections.

4.1.1 Alternatives to Simulate

PACSM-simulated water surface elevations and calculated residence times were reviewed to support selection of alternatives to simulate. Figure 29 presents daily water surface elevations for each alternative for the PACSM simulation period of 1947 through 1991. Figure 30 presents the annual average residence time in the reservoir for each of the alternatives using PACSM annual average contents and outflows. As shown in these two figures, alternatives generally fall into two groups – “operation of the existing reservoir” (Base285, No Action, and Full Use) and “operation of an expanded reservoir” (Alt1a, Alt13a, Alt10a, and Alt1c).

It was decided that two alternatives would be simulated - a base case type model run and the alternative which consistently exhibits the greatest water level difference relative to the base case. The outflow temperature effect difference between these two alternatives is assumed to be the maximum difference among alternatives being considered for the EIS. Among the “operation of the existing reservoir” alternatives, Base285 (Existing Supply/ Existing Demand) exhibits the lowest average water surface elevation. Among the “operation of an expanded reservoir” alternatives, Alt1a exhibits the highest average water surface elevations and the highest residence times. Therefore, the following alternatives were identified for paired simulations:

- Existing Supply / Existing Demand (Base 285); and

- Proposed Alternative 1A.

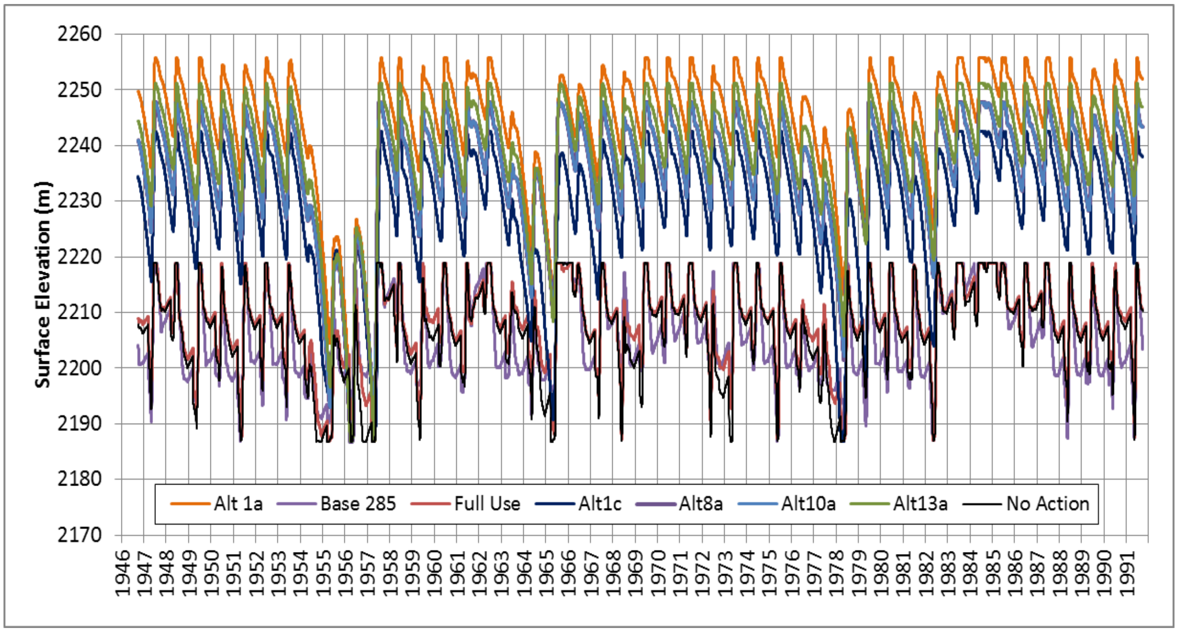

Figure 29. PACSM Daily Surface Water Elevation of Gross Reservoir for PFEIS Alternatives

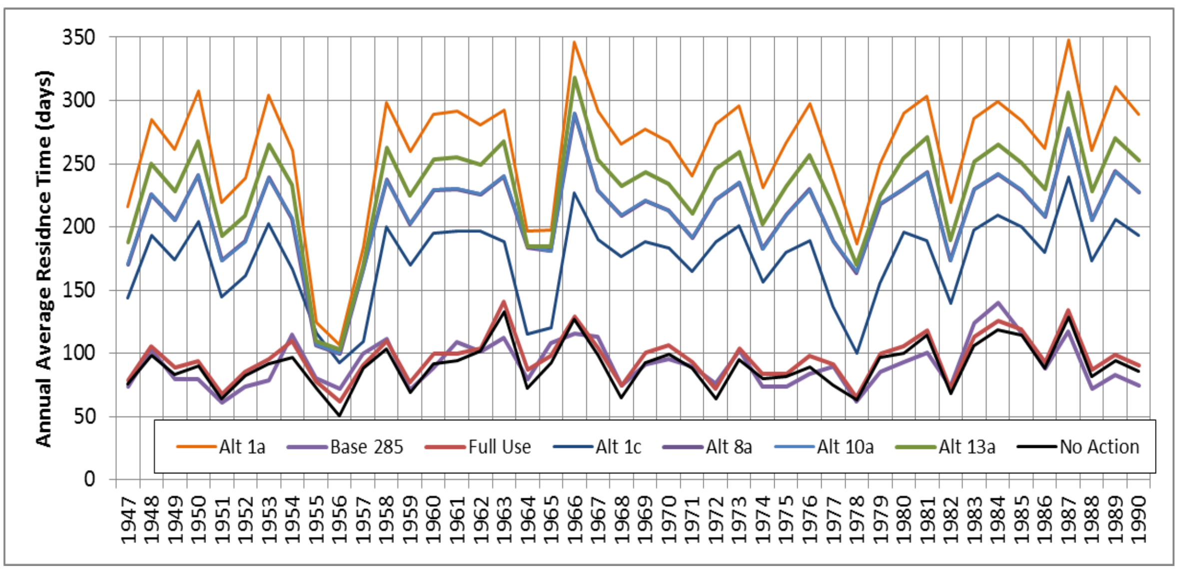

Figure 30. Residence Time for Gross Reservoir for PFEIS Alternatives Based on Annual PACSM Contents and Outflow Rates

4.1.2 Hydrologic Years to Simulate

The stated temperature concern by CDPHE for Gross Reservoir (CDPHE, 2012a) was that the greater reservoir depth could lead to colder outlet temperatures. Simulation of the calibration years (2011 and 2012) was not an option because there are no available simulated hydrologic input data (PACSM, Platte and Colorado Simulation Model) for the alternatives. Thus, an analysis was conducted over the full PACSM hydrologic simulation period (1947-1991) to identify the year with the greatest difference in average summertime reservoir surface water elevation between Base 285 and the proposed alternative (Alt1a). This year was found to be 1972, with an average summertime water level difference between Base285 and Alt1a of 44 m (144 ft). In addition, years that were approximately equal to the median difference in summertime surface water elevation over the 44 years were identified. The year preceding 1972 (1971) was found to be such a year. Therefore, it was determined that model runs would be conducted using simulated hydrology and operations (from the hydrologic model) for the two consecutive calendar years of 1971 and 1972. This would allow a continuous two-year run with the model and provide results over a range of water level differences from Base285 to Alt1a.

Predicted daily reservoir surface elevations for 1971 and 1972 for Base285 and Alt1a are presented in Figure 31. A trace of the 2011 and 2012 (calibration period) surface water levels is also presented for comparison.

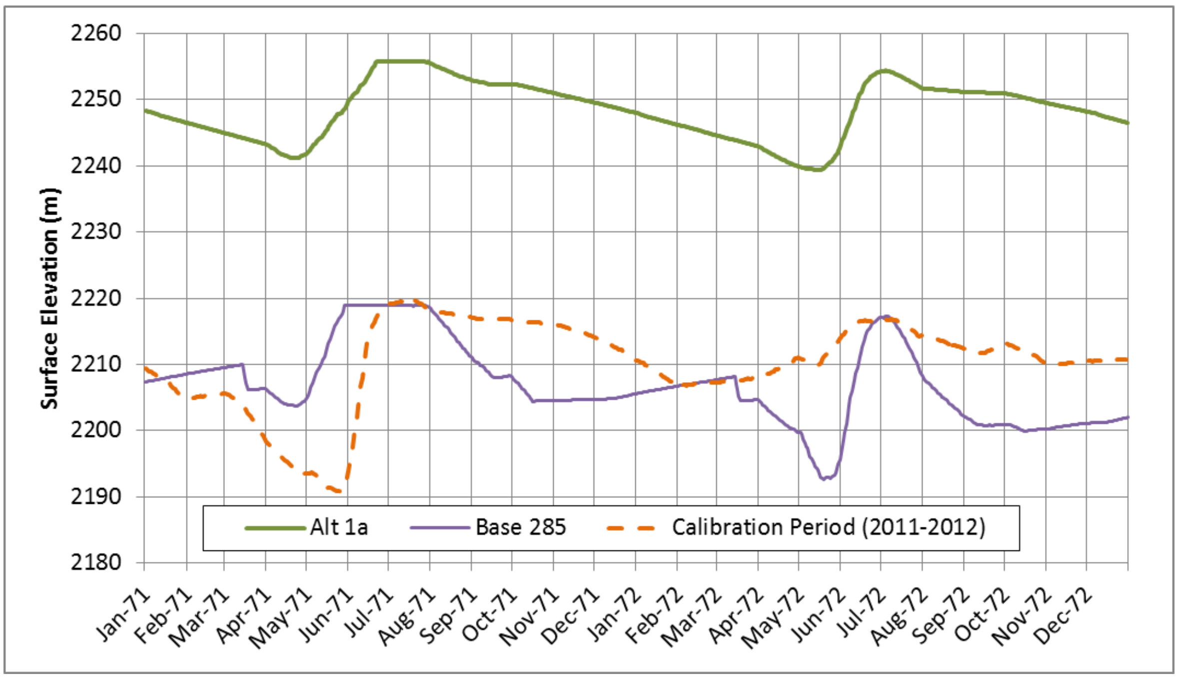

Figure 31. Daily Water Surface Elevations in Gross Reservoir for 1971 and 1972 PACSM Hydrology, Base285 and Alt1a

Reservoir inflow rates from PACSM for these two years are presented in Figure 32 for Base285 and Alt1a. A trace of the 2011 and 2012 observed calibration period inflow rates is also presented for comparison. While surface elevation differences between Base285 and Alt1a were greater for 1972, inflow rate differences were greater in 1971, due to PACSM-simulated differences in Moffat Tunnel operations.

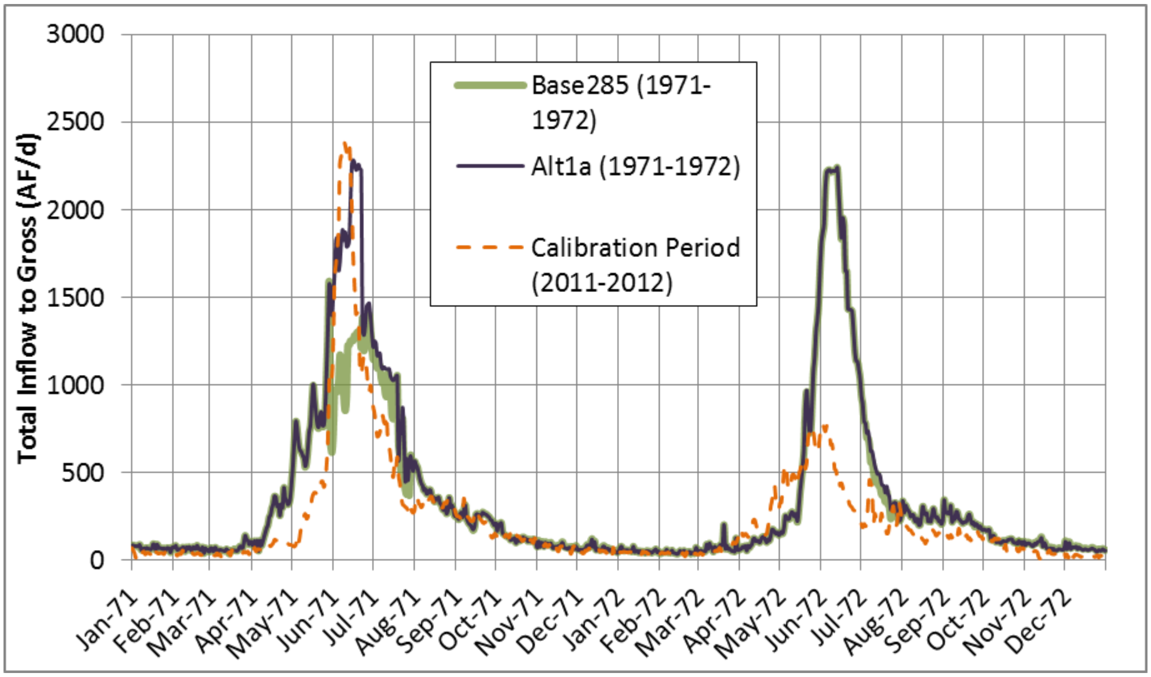

Figure 32. Daily Inflow Rates for Gross Reservoir for 1971 and 1972 PACSM Hydrology, Base285 and Alt1a

4.1.3 Assumed Meteorological Conditions

Detailed observed meteorological data near Gross Reservoir for all the required model inputs (wind speed and direction, air temperature, dew point, and solar radiation) are not available for the hydrologic years of 1971 and 1972. Therefore, it was decided that recent observed data would be applied to the simulations. From the datasets near Gross Reservoir (discussed in Section 2.2.2), 2009 was selected as a relatively cold year, and 2012 was selected as a warm year. Average maximum daily summertime air temperatures, as one measure of relative air temperatures, are presented for recent years in Figure 33. Meteorological inputs were developed to support the consecutive two-year (1971-1972) simulations by repeating 2009 inputs twice for one set of runs and repeating 2012 inputs twice for the other set of runs.

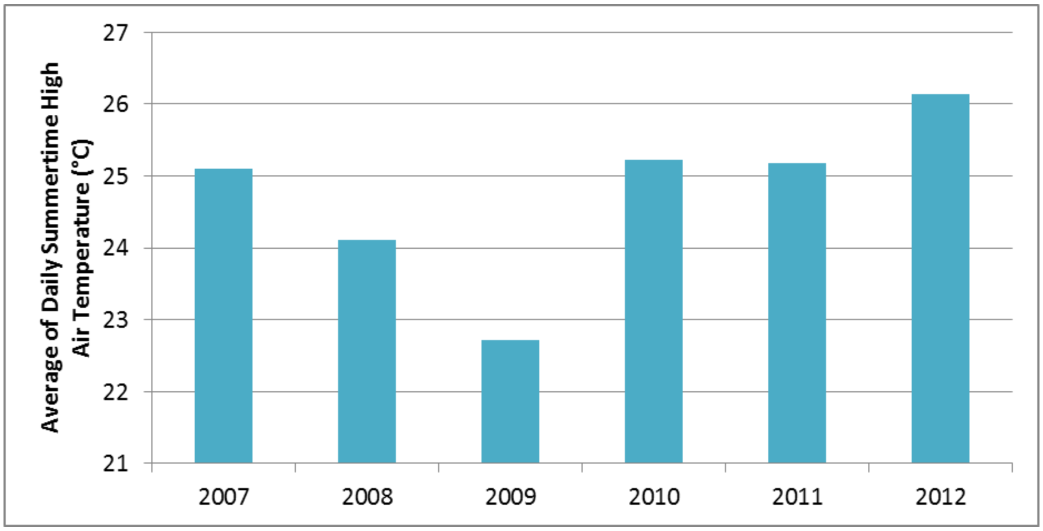

Figure 33. Average of Daily Maximum Air Temperatures Observed at Gross Reservoir Dam, 2007 through 2012

4.1.4 Assumed Inflow Water Temperatures

In an attempt to best match the approach taken in calibration to estimate inflow water temperatures to the reservoir, a set of monthly averages of observed water temperatures from Pinecliffe was compiled. Monthly average values were set to mid-month points, and daily inflow temperatures were linearly interpolated between these values. Where inflow volumes exceeded 992 AF/d (500 cfs), monthly average values were replaced with a value of 4.75 °C. Given the concerns about inflow water temperature data described in Section 3.3.2.1, this input represents the greatest uncertainty in the model application. However, the approach described here is applied consistently, which lends itself to the intended comparative approach to analysis of results and mimics the approach taken during calibration, which successfully recreated observed outflow temperature data. The resulting input inflow water temperatures for Alt1a and Base285 are exactly the same, as presented in Figure 34 along with a trace of the 2011 and 2012 input inflow water temperatures. Inflow temperatures for Base285 and Alt1a are also fairly similar to calibration inputs for 2011 and 2012, though temperatures were consistently warmer for 2012, which would be expected for the very low inflow rates of that year.

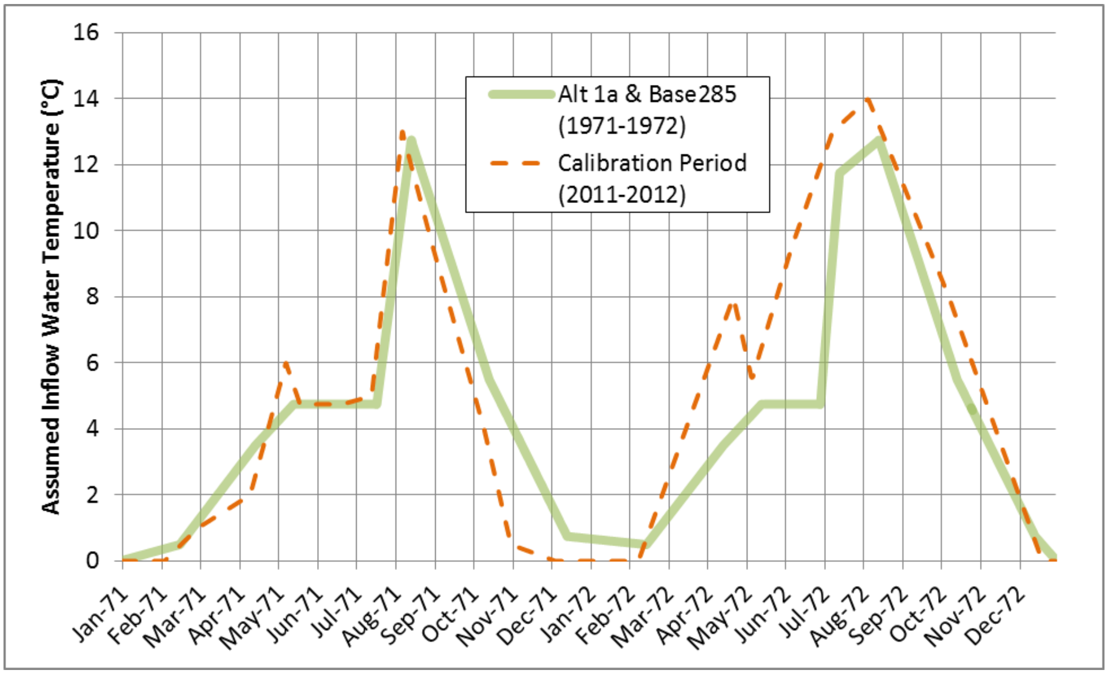

Figure 34. Assumed Inflow Water Temperatures for Base285 and Alt1a Runs with 1971-1972 PACSM Hydrology

4.1.5 List of Proposed Model Runs

From determination of EIS alternatives, PACSM hydrologic years, meteorological conditions, and inflow water temperature assumptions, a total of four model runs were defined to assess potential effects of the proposed reservoir expansion on outflow water temperatures. Each run was simulated for a consecutive two-year period. Initial conditions were set to uniform water temperatures matching calibration assumptions. Initial water levels in the reservoir were set to match corresponding PACSM run values for January 1, 1971. The model runs were defined as:

Run 1. Base 285, 1971-1972 PACSM hydrology, 2009 meteorological conditions[9] (cooler year),
Run 2. Base 285, 1971-1972 PACSM hydrology, 2012 meteorological conditions (warmer year),
Run 3. Alt1a, 1971-1972 PACSM hydrology, 2009 meteorological conditions (cooler year), and
Run 4. Alt1a, 1971-1972 PACSM hydrology, 2012 meteorological conditions (warmer year).

Simulated outflow temperature results from Run 1 were intended for comparison to Run 3, and results from Run 2 were intended for comparison to Run 4. Additionally comparison between Run 1 and Run 2 and between Run 3 and Run 4 were anticipated to evaluate the relative influence of the meteorology on the outflow response.

[9] Specified meteorological conditions were repeated for the two consecutive years within each run.

4.2 MODEL APPLICATION RESULTS

The calibrated model was applied to simulate the four scenarios described in the preceding subsection. Analysis of results focused on simulated outflow temperatures. First, results were compared to assess the effects of the two different meteorological conditions (2009 [cooler] air temperatures and 2012 [warmer] air temperatures). Next, Base 285 and Alt1a results were compared.

4.2.1 Meteorological Condition Effects

As discussed in Section 4.1.3, each two-year simulation was run with two sets of meteorological assumptions to assess response sensitivity to meteorology. Outflow temperature predictions for the Base285 (Existing Supply/ Existing Demand) simulations for 1971 and 1972 PACSM-simulated hydrology for 2009 (cooler air temperatures) and 2012 (warmer air temperatures) meteorological conditions are presented in Figure 35.

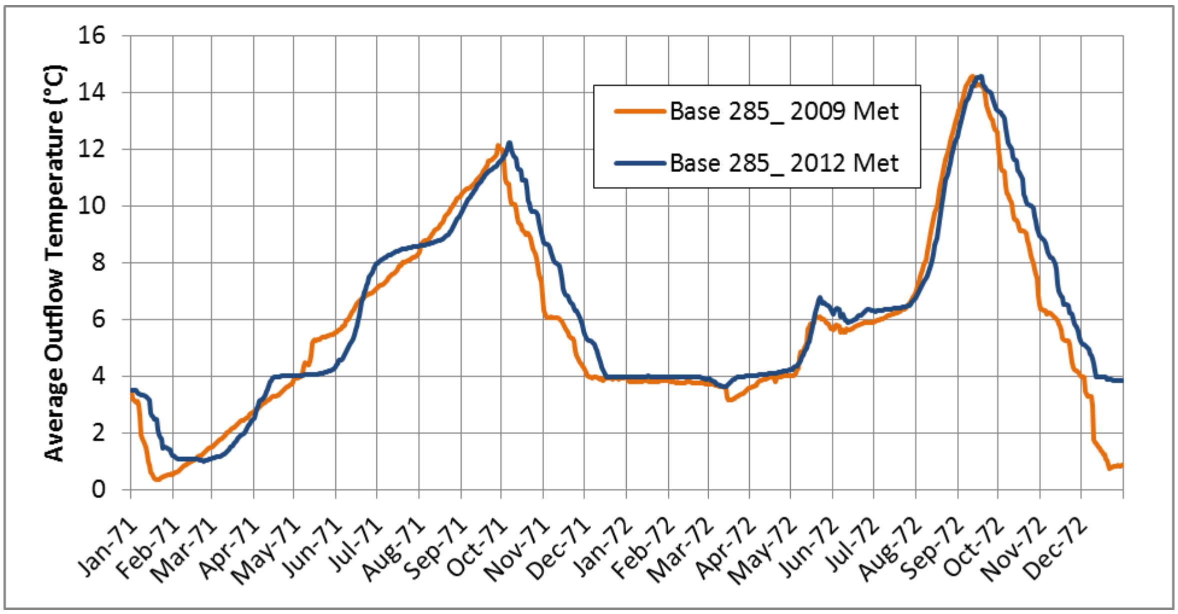

Figure 35. Simulated Outflow Temperatures from Gross Reservoir for Base285, 1971-1972, 2009 and 2012 Meteorological Inputs

Overall, results for outflow temperatures are similar between the two runs with different meteorological inputs. The warmer air temperatures of 2012 resulted in an annual average of 0.4°C warmer water in the outflow, as compared to the simulation results with 2009 air temperatures. The difference occurs primarily in the fall and winter, with an average of 0.1°C difference in outflow temperatures during summer months of July through September.

Outflow temperature predictions for the Alt1a runs (2009 and 2012 meteorological conditions) are presented in Figure 36. Again results for outflow temperatures are similar between the two runs with different meteorological inputs. The warmer air temperatures of 2012 resulted in an annual average of 0.6˚C warmer water in the outflow; although the peak outflow temperature for the 1971 hydrology was slightly higher with the 2009 air temperatures.

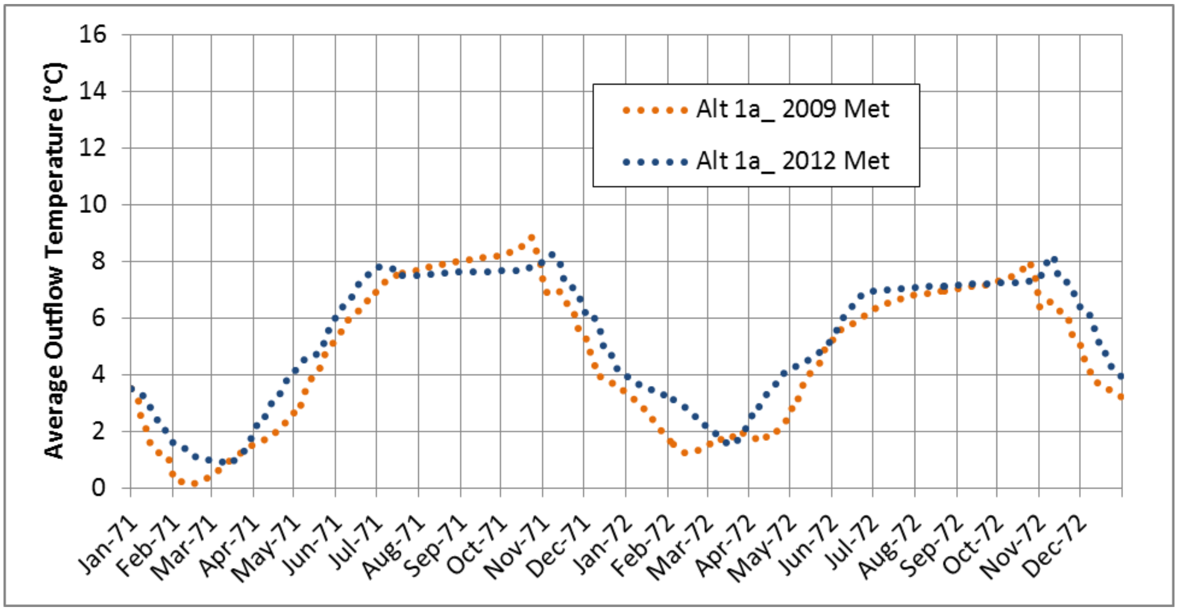

Figure 36. Simulated Outflow Temperatures from Gross Reservoir for Alt1a, 1971-1972, 2009 and 2012 Meteorological Inputs

While review of simulated profiles shows cooler surface temperatures for the 2009 meteorological inputs as compared to the 2012 meteorological inputs for both Base285 and Alt1a, the outflow temperatures do not vary widely between the two simulations, particularly during the period of summer stratification. The most significant effect appears to be a slightly earlier turnover (one to two weeks earlier) for 2009 meteorological conditions as opposed to 2012 meteorological conditions.

4.2.2 Reservoir Expansion Effects

Direct comparison of Base285 and Alt1a simulations were made to assess the relative effect of operation of an expanded reservoir on outflow water temperatures. Figure 37 and Figure 38 present simulation results for outflow water temperatures for Base285 and Alt1a for the 1971-1972 simulation period. Two plots are shown to present both sets of meteorological inputs tested, though, as discussed above, the response in outflow temperatures did not vary much with the different meteorological inputs.

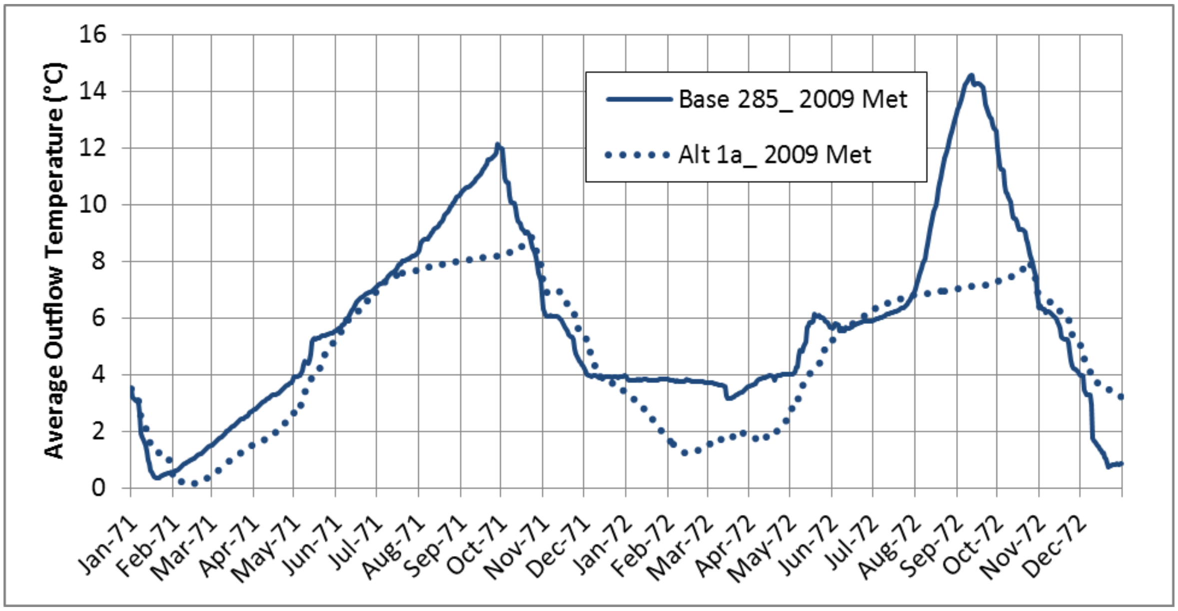

Figure 37. Simulated Outflow Temperatures from Gross Reservoir for Base285 and Alt1a, 1971-1972, 2009 Meteorological Inputs

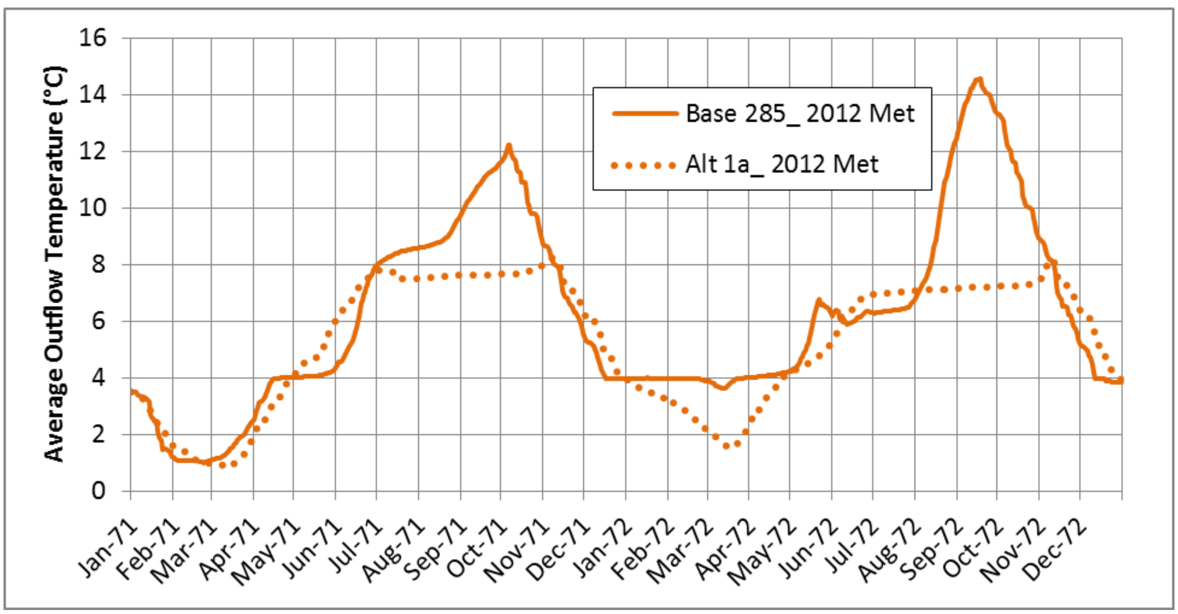

Figure 38. Simulated Outflow Temperatures from Gross Reservoir for Base285 and Alt1a, 1971-1972, 2012 Meteorological Inputs

Results in these plots show that the model predicts cooler summer and peak outflow temperatures for the expanded reservoir. For the 2009 meteorological inputs, the overall decrease in peak temperature was simulated to be 3.3 ˚C for 1971 and 6.6˚C for 1972. For the 2012 meteorology, the decrease in peak temperatures was simulated to be 4.0˚C in 1971 and 6.4˚C in 1972. For the 2009 meteorology, the maximum outflow temperature decreased from 14.6˚C to 8.9˚C for the full simulation (14.6˚C to 8.3˚C for the 2012 meteorology). The timing of turnover is also predicted to be delayed by approximately one month for the expanded reservoir for these two years. Table 1 provides summary statistics of the outflow temperature results.

Table 1. Summary of Outflow Temperature Differences for Simulated Alternatives

Metric	1971 (2009 met/ 2012 met)	1972 (2009 met/ 2012 met)	1971 through 1972 (2009 met/ 2012 met)
Difference in Average Annual Outflow Temperature (Alt1a vs. Base285)	-0.7˚C / -0.5˚C	-1.4˚C / -1.3˚C	-1.1˚C / -0.9˚C
Difference in July-Sept. Average Outflow Temperature (Alt1a vs. Base285)	-1.6˚C / -1.7˚C	-3.1˚C / -2.7˚C	-2.4˚C / -2.2˚C
Base285 Max Outflow Temperature	12.1˚C / 12.2˚C	14.6˚C / 14.6˚C	14.6˚C / 14.6˚C
Alt1a Max Outflow Temperature	8.9˚C / 8.3˚C	8.0˚C / 8.2˚C	8.9˚C / 8.3˚C

Generally, greater differences in outflow temperature are predicted for 1972 hydrology, due to larger differences in water surface elevations between Alt1a and Base285 during the period of summer stratification. However, the specific temperature predictions for Alt1a for 1971 and 1972 are similar, with peak outflow temperatures within 1˚C and similar timing of turnover. This result may suggest that the expanded reservoir could exhibit more consistent outflow temperatures from year to year, in addition to cooler outflow temperatures.

These outflow temperature results reflect the simulated temperature and size of the hypolimnion with expansion of the reservoir. The larger hypolimnion maintains cooler temperatures during summer stratification. The larger volume of cooler water warms less during the summer through contact with the metalimnion and maintains stratification longer. Further, the increased volume of hypolimnion is not accompanied by a comparable increase in outflow from the hypolimnion. While the average annual contents (1946-1991 PACSM) of the reservoir for Alt1a are anticipated to increase by 223%, average annual outflow volumes are expected to increase by only 11%. Essentially, for the expanded reservoir there is a greater volume of cold water maintained in the hypolimnion of the reservoir, and this larger hypolimnion largely maintains its cool temperatures through the summer, resulting in cooler release temperatures from the bottom of the reservoir.

5 SUMMARY AND RECOMMENDATIONS

As part of the Moffat Collection System Project (USACE, 2012), Denver Water is proposing to enlarge Gross Reservoir by raising the dam height from 340 feet to 465 feet. This will nearly triple the storage volume, adding 72,000 AF of storage for a total of 113,811 AF. This increase in storage volume will also roughly double the reservoir footprint at capacity, from 418 acres to 818 acres (USACE, 2012). The objective of the work described in this report was to develop and apply a numerical model to anticipate potential effects on outlet water temperatures of the proposed expansion of Gross Reservoir (PFEIS Proposed Alternative 1a [Alt1a]). The water-quality concern prompting model development and application is that expansion of the reservoir could lead to colder release temperatures, resulting in aquatic life concerns in South Boulder Creek below the dam. This report does not attempt to interpret the effects to aquatic life of the predicted changes to water temperature.

A numerical model of Gross Reservoir was developed using the modeling software CE-QUAL-W2 (version 3.6). CE-QUAL-W2 is a two-dimensional hydrodynamic and water-quality model. The model was calibrated to observed continuous outflow temperature data from calendar years 2011 and 2012. Observed temperature profile data were also compared to model outputs. The calibration period was selected based on availability of observed data. The calibration period includes a very high runoff year (2011) and a low runoff year (2012), for a wide range of hydrologic conditions. A good calibration of water temperature was achieved for the full calibration period. The model produced an excellent match of outflow temperatures (AME < 0.2°C and RMSE < 0.4°C). The model also produced good matches of observed temperature profile data near the dam and near the inlet in both years, including epilimnion thickness and seasonal temperature change patterns. Given the wide range of conditions in these two consecutive calibration years (wide range of inflow volumes and water level patterns), the consistently good simulation of water temperatures offers a high degree of confidence in simulation results.

5.1 MODEL APPLICATION FINDINGS

The calibrated model was applied to simulate the outflow temperatures for the proposed expansion of Gross Reservoir for the Proposed Alternative (Alt1a) in the PFEIS (USACE, 2012). Results were compared to simulated outflow results for Base285 (Existing Supply / Existing Demand). A two year period of the PACSM results (1971-1972) was selected that included the year with the maximum difference (between Base285 and Alt1a) in average summertime (July-September) water surface elevation and a year close to the median difference. Each hydrologic scenario was run twice, once with cooler meteorological inputs (2009 observed) and once with warmer meteorological inputs (2012 observed). Assumed inflow water temperatures were developed using monthly average values from Pinecliffe and findings from the calibration effort. The model runs were as follows:

Run 1. Base285, 1971-1972 PACSM hydrology, 2009 meteorological conditions (cooler year);
Run 2. Base285, 1971-1972 PACSM hydrology, 2012 meteorological conditions (warmer year);
Run 3. Alt1a, 1971-1972 PACSM hydrology, 2009 meteorological conditions (cooler year); and
Run 4. Alt1a, 1971-1972 PACSM hydrology, 2012 meteorological conditions (warmer year).

Simulation results demonstrate that the outflow temperature response was not highly sensitive to meteorological inputs. The observed effects were primarily attributable to the reservoir expansion. Figure 39 presents model results for the 2009 meteorological input (Run 1 and Run 3).

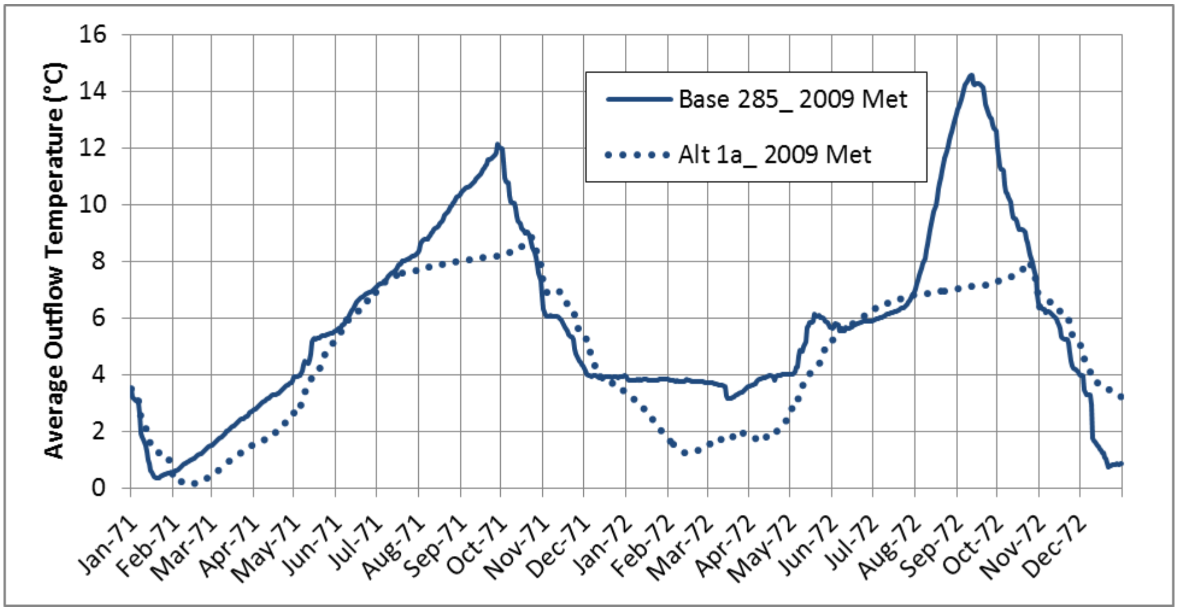

Figure 39. Simulated Outflow Temperatures from Gross Reservoir for Base285 and Alt1a, 1971-1972, 2009 Meteorological Inputs

The model predicts cooler summer and peak outflow temperatures for the expanded reservoir. The largest decrease in peak temperature for 1972 was simulated to be -6.6˚ C (for the 2009 meteorological inputs). The largest decrease in peak temperature for 1971 was simulated to be -4.0˚C (for 2012 meteorological input). These simulated decreases in peak temperatures result in maximum outflow temperatures below 8.9˚C for Alt 1a, regardless of meteorological assumptions. The timing of turnover is also predicted to be delayed by approximately one month for the expanded reservoir for these two years. Table 2 provides summary statistics of the outflow temperature results for the full simulation period of 1971 through 1972.

Table 2. Summary of 1971 through 1972 Outflow Temperature Differences for Simulated Alternatives

Metric	1971 through 1972 (2009 met/ 2012 met)
Difference in Average Annual Outflow Temperature (Alt1a vs. Base285)	-1.1°C / -0.9°C
Difference in July-Sept. Average Outflow Temperature (Alt1a vs. Base285)	-2.4°C / -2.2°C
Base 285 Max Outflow Temperature	14.6°C / 14.6°C
1A Max Outflow Temperature	8.9°C / 8.3°C

5.2 RECOMMENDATIONS

The available dataset for the model was found to be good overall, with continuous outflow temperature data and good in-reservoir profile data. Through the process of model development and testing however, one recommendation was generated for future data collection to reduce uncertainty in future numerical analysis of temperature in the reservoir. If there is any anticipated need to continue modeling of temperature in the future, it is recommended that a temperature probe be deployed to collect year-round continuous temperature data at the inflow location to the reservoir on South Boulder Creek. Only a handful of inflow temperature data observation are collected each year from a location a few miles upstream from the reservoir, and this was a very sensitive input and the key data uncertainty identified in model development.

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6 REFERENCES

Bolsenga, S.J. Total Albedo of Great Lakes Ice. Water Resources Research. Vol. 5; Issue 5; pp 1132-1133. October, 1969.

Bray, T. 2013. Email communication to J.M. Boyer. Transmittal of Area-Elevation-Volume Relationship to Hydros. March 11, 2013.

Colorado Department of Public Health and Environment (CDPHE). 2012a. Moffat Collection System PFEIS Comments. Letter to Martha Chieply, Regulatory Chief, Omaha District, U.S. Army Corp of Engineers; From Martha Rudolph, Martha E. Rudolph, Director of Environmental Programs, CDPHE. December 24, 2012.

Colorado Department of Public Health and Environment (CDPHE). 2012b. Colorado's 303(D) List of Impaired Waters and Monitoring and Evaluation List. 5 CCR 1002-93 (Regulation 93). Water Quality Control Commission. Amended February 13, 2011; Effective March 30, 2012.

CDPHE. 2013. Classifications and Numeric Standards for South Platte River Basin, Laramie River Basin Republican River Basin, Smoky Hill River Basin. 5CCR 1002-38 (Regulation 38). Water Quality Control Commission. Amended and effective May 13, 2013.

Chapra, S.C. and J. Martin. 2004. Lake2K: A Modeling Framework for Simulating Lake Water Quality, v 1.2. User's Manual and Documentation. Civil and Environmental Engineering Department, Tufts University, Medford, MA. July 16, 2004.

Cole, T.M., and S. A. Wells. 2008. "CE-QUAL-W2: A two-dimensional, laterally averaged, Hydrodynamic and Water Quality Model, Version 3.6," Department of Civil and Environmental Engineering, Portland State University, Portland, OR.

Hale, B. 2013. Email communication to T. Bray. "Water quality sampling at Pinecliffe". July 17, 2013.

Hydros Consulting Inc. (Hydros). 2013. Technical Memorandum to USACE, URS, and Denver Water. Proposed Approach for Analysis of Gross Reservoir Water Temperature. April 11. 2013.

Lewis, W.M. and Saunders, J.F. III. Analysis of potential for Warming of South Boulder Creek below Gross Reservoir. Prepared for: Denver Water Department. September 29, 1998.

MWH. 2005. Technical Memoranda. Final Draft Alternative Descriptions for the Moffat Collection System Project EIS. August.

Portillo, D. 2013. Email communication to T. Adams. Transmittal of Gross Reservoir Contour Maps to Hydros. April 2, 2013.

U.S. Army Corps of Engineers (USACE). 2012. Preliminary Final Environmental Impact Statement: Moffat Collection System Project; Denver Water. September, 2012.

Walter, I. A., Allen, R. G. ., R. Elliott, M. E. Jensen, D. Itenfisu, B. Mecham, T. A. Howell, R. Snyder, P. Brown, S. Eching, T. Spofford, M. Hattendorf, R. H. Cuenca, J. L. Wright and D. Martin. 2002. "The ASCE Standardized Reference Evapotranspiration Equation." Environmental and Water Resources Institute of the American Society of Civil Engineers.

Appendix A: Simulated Daily Outflow Temperatures

This appendix presents tables of simulated daily reservoir outflow temperatures for the four simulations described in Section 4 of the main report.

all ˚C	2009 Meteorology		2012 Meteorology	
Date	**Base285**	**Alt1a**	**Base285**	**Alt1a**
1/1/1971	3.5	3.5	3.5	3.5
1/2/1971	3.22	3.37	3.5	3.5
1/3/1971	3.12	3.28	3.49	3.48
1/4/1971	3.09	3.24	3.49	3.45
1/5/1971	3.1	3.16	3.4	3.4
1/6/1971	2.97	3.06	3.39	3.38
1/7/1971	2.61	2.8	3.37	3.36
1/8/1971	1.92	2.49	3.32	3.33
1/9/1971	1.78	2.38	3.34	3.28
1/10/1971	1.7	2.31	3.31	3.23
1/11/1971	1.5	2.13	3.29	3.2
1/12/1971	1.29	1.94	3.26	3.16
1/13/1971	0.99	1.76	3.19	3.08
1/14/1971	0.86	1.68	3.14	2.96
1/15/1971	0.62	1.54	2.7	2.81
1/16/1971	0.55	1.47	2.62	2.74
1/17/1971	0.47	1.42	2.58	2.69
1/18/1971	0.38	1.34	2.47	2.61
1/19/1971	0.34	1.29	2.47	2.49
1/20/1971	0.35	1.26	2.1	2.37
1/21/1971	0.36	1.24	1.91	2.33
1/22/1971	0.41	1.24	1.83	2.28
1/23/1971	0.44	1.25	1.8	2.24
1/24/1971	0.44	1.23	1.47	2.11
1/25/1971	0.48	1.22	1.51	2.06
1/26/1971	0.49	1.19	1.49	2.04
1/27/1971	0.5	1.18	1.47	1.93
1/28/1971	0.5	1.08	1.42	1.86
1/29/1971	0.51	0.85	1.43	1.76
1/30/1971	0.55	0.65	1.28	1.66
1/31/1971	0.53	0.51	1.21	1.64
2/1/1971	0.56	0.44	1.21	1.6
2/2/1971	0.59	0.38	1.16	1.54
2/3/1971	0.62	0.26	1.11	1.51
2/4/1971	0.66	0.19	1.09	1.51
2/5/1971	0.69	0.19	1.09	1.5
2/6/1971	0.73	0.21	1.08	1.48
2/7/1971	0.77	0.22	1.08	1.45
2/8/1971	0.8	0.23	1.07	1.44
2/9/1971	0.85	0.23	1.07	1.42
2/10/1971	0.87	0.19	1.08	1.39
2/11/1971	0.89	0.18	1.07	1.3
2/12/1971	0.93	0.17	1.07	1.2
2/13/1971	0.97	0.16	1.07	1.19
2/14/1971	0.99	0.15	1.06	1.18
2/15/1971	1.03	0.14	1.07	1.17
2/16/1971	1.05	0.14	1.07	1.1
2/17/1971	1.08	0.17	1.07	1.11
2/18/1971	1.11	0.18	1.07	1.09
2/19/1971	1.14	0.2	1.06	1.07
2/20/1971	1.19	0.21	1.04	1.04
2/21/1971	1.22	0.21	1.05	1.02
2/22/1971	1.26	0.25	1.01	1.02
2/23/1971	1.29	0.26	1	1.02
2/24/1971	1.33	0.28	1.01	1.02
2/25/1971	1.36	0.32	1.02	1.01
2/26/1971	1.4	0.35	1.03	1.01
2/27/1971	1.44	0.38	1.07	1
2/28/1971	1.48	0.39	1.08	1
3/1/1971	1.52	0.42	1.1	0.99
3/2/1971	1.55	0.47	1.12	0.99
3/3/1971	1.6	0.52	1.12	0.98

all ˚C	2009 Meteorology		2012 Meteorology	
Date	**Base285**	**Alt1a**	**Base285**	**Alt1a**
3/4/1971	1.64	0.55	1.14	0.97
3/5/1971	1.68	0.59	1.15	0.95
3/6/1971	1.73	0.62	1.15	0.95
3/7/1971	1.77	0.66	1.17	0.94
3/8/1971	1.81	0.7	1.22	0.93
3/9/1971	1.86	0.74	1.24	0.91
3/10/1971	1.89	0.77	1.25	0.9
3/11/1971	1.94	0.81	1.29	0.87
3/12/1971	1.99	0.85	1.34	0.86
3/13/1971	2.02	0.89	1.38	0.84
3/14/1971	2.07	0.93	1.43	0.82
3/15/1971	2.11	0.95	1.48	0.85
3/16/1971	2.16	0.98	1.55	0.91
3/17/1971	2.2	1	1.61	0.96
3/18/1971	2.24	1.04	1.67	1.02
3/19/1971	2.27	1.07	1.72	1.07
3/20/1971	2.32	1.12	1.81	1.1
3/21/1971	2.34	1.15	1.86	1.11
3/22/1971	2.38	1.19	1.89	1.14
3/23/1971	2.42	1.24	1.91	1.2
3/24/1971	2.44	1.26	1.96	1.26
3/25/1971	2.48	1.29	2.02	1.34
3/26/1971	2.52	1.33	2.09	1.42
3/27/1971	2.53	1.37	2.19	1.47
3/28/1971	2.58	1.41	2.27	1.54
3/29/1971	2.63	1.43	2.31	1.62
3/30/1971	2.68	1.45	2.38	1.7
3/31/1971	2.71	1.51	2.43	1.8
4/1/1971	2.77	1.55	2.53	1.89
4/2/1971	2.79	1.57	2.69	2
4/3/1971	2.84	1.62	2.85	2.17
4/4/1971	2.88	1.62	2.93	2.35
4/5/1971	2.9	1.63	3.1	2.49
4/6/1971	2.93	1.63	3.17	2.49
4/7/1971	2.98	1.64	3.17	2.49
4/8/1971	3.03	1.66	3.22	2.48
4/9/1971	3.07	1.71	3.31	2.52
4/10/1971	3.1	1.76	3.44	2.61
4/11/1971	3.14	1.82	3.56	2.71
4/12/1971	3.18	1.84	3.69	2.81
4/13/1971	3.21	1.86	3.78	2.89
4/14/1971	3.24	1.9	3.85	2.96
4/15/1971	3.27	1.9	3.92	3.06
4/16/1971	3.29	1.93	3.96	3.11
4/17/1971	3.3	1.98	3.97	3.13
4/18/1971	3.32	2.03	3.98	3.17
4/19/1971	3.35	2.03	3.99	3.22
4/20/1971	3.38	2.01	3.99	3.29
4/21/1971	3.41	2.08	4	3.36
4/22/1971	3.47	2.13	4	3.46
4/23/1971	3.51	2.21	4	3.57
4/24/1971	3.56	2.27	4	3.68
4/25/1971	3.61	2.33	4.01	3.8
4/26/1971	3.62	2.4	4.01	3.91
4/27/1971	3.66	2.46	4.01	3.98
4/28/1971	3.7	2.48	4.01	3.99
4/29/1971	3.73	2.47	4.02	4.02
4/30/1971	3.81	2.56	4.02	4.07
5/1/1971	3.92	2.65	4.02	4.1
5/2/1971	3.92	2.78	4.02	4.16
5/3/1971	3.93	2.93	4.02	4.23
5/4/1971	3.98	2.92	4.02	4.33

all ° C	2009 Meteorology		2012 Meteorology	
Date	**Base285**	**Alt1a**	**Base285**	**Alt1a**
5/5/1971	3.99	2.88	4.03	4.41
5/6/1971	4.07	2.95	4.03	4.48
5/7/1971	4.14	3.08	4.03	4.52
5/8/1971	4.35	3.24	4.04	4.53
5/9/1971	4.46	3.35	4.04	4.54
5/10/1971	4.44	3.53	4.04	4.56
5/11/1971	4.41	3.61	4.05	4.57
5/12/1971	4.52	3.71	4.05	4.59
5/13/1971	4.74	3.8	4.05	4.61
5/14/1971	5.15	3.93	4.06	4.63
5/15/1971	5.23	3.99	4.06	4.65
5/16/1971	5.29	3.99	4.06	4.68
5/17/1971	5.26	4.02	4.06	4.71
5/18/1971	5.27	4.04	4.07	4.74
5/19/1971	5.29	4.13	4.09	4.76
5/20/1971	5.34	4.32	4.08	4.85
5/21/1971	5.39	4.47	4.11	5.04
5/22/1971	5.38	4.56	4.11	5.05
5/23/1971	5.39	4.63	4.12	5.1
5/24/1971	5.39	4.73	4.13	5.2
5/25/1971	5.4	4.81	4.15	5.5
5/26/1971	5.43	4.87	4.19	5.55
5/27/1971	5.44	4.91	4.19	5.6
5/28/1971	5.46	4.97	4.22	5.68
5/29/1971	5.47	5.06	4.23	5.75
5/30/1971	5.52	5.16	4.27	5.91
5/31/1971	5.53	5.24	4.3	5.97
6/1/1971	5.56	5.34	4.38	6.04
6/2/1971	5.58	5.43	4.42	6.24
6/3/1971	5.62	5.48	4.56	6.24
6/4/1971	5.66	5.52	4.58	6.31
6/5/1971	5.77	5.6	4.61	6.37
6/6/1971	5.77	5.67	4.7	6.45
6/7/1971	5.82	5.8	4.78	6.48
6/8/1971	5.96	5.87	4.87	6.52
6/9/1971	5.98	5.9	4.94	6.56
6/10/1971	6.02	5.94	5.02	6.69
6/11/1971	6.09	5.98	5.1	6.71
6/12/1971	6.27	6.06	5.25	6.75
6/13/1971	6.33	6.12	5.31	6.86
6/14/1971	6.39	6.14	5.44	6.94
6/15/1971	6.48	6.16	5.61	7.04
6/16/1971	6.55	6.2	5.74	7.08
6/17/1971	6.6	6.24	5.97	7.17
6/18/1971	6.66	6.26	6.14	7.19
6/19/1971	6.72	6.3	6.67	7.23
6/20/1971	6.75	6.38	6.74	7.32
6/21/1971	6.77	6.45	6.93	7.42
6/22/1971	6.82	6.51	7.03	7.42
6/23/1971	6.85	6.53	7.2	7.46
6/24/1971	6.87	6.61	7.31	7.49
6/25/1971	6.89	6.64	7.49	7.53
6/26/1971	6.92	6.67	7.56	7.63
6/27/1971	6.94	6.72	7.69	7.61
6/28/1971	7	6.82	7.8	7.66
6/29/1971	7.05	6.93	7.9	7.68
6/30/1971	7.08	6.9	7.95	7.72
7/1/1971	7.12	7.02	7.99	7.74
7/2/1971	7.16	7.07	8.03	7.78
7/3/1971	7.2	7.13	8.06	7.79
7/4/1971	7.21	7.14	8.11	7.79
7/5/1971	7.26	7.2	8.15	7.8

all ˚C	2009 Meteorology		2012 Meteorology	
Date	**Base285**	**Alt1a**	**Base285**	**Alt1a**
7/6/1971	7.29	7.26	8.18	7.8
7/7/1971	7.33	7.31	8.2	7.8
7/8/1971	7.38	7.34	8.23	7.79
7/9/1971	7.47	7.37	8.25	7.78
7/10/1971	7.49	7.4	8.27	7.76
7/11/1971	7.53	7.43	8.29	7.75
7/12/1971	7.6	7.45	8.33	7.75
7/13/1971	7.64	7.46	8.35	7.73
7/14/1971	7.67	7.49	8.38	7.7
7/15/1971	7.73	7.49	8.39	7.67
7/16/1971	7.81	7.53	8.41	7.64
7/17/1971	7.89	7.57	8.43	7.61
7/18/1971	7.89	7.57	8.44	7.59
7/19/1971	7.92	7.58	8.47	7.56
7/20/1971	8.01	7.6	8.49	7.52
7/21/1971	8.02	7.61	8.49	7.51
7/22/1971	8.05	7.62	8.5	7.49
7/23/1971	8.07	7.63	8.52	7.51
7/24/1971	8.09	7.63	8.52	7.51
7/25/1971	8.11	7.64	8.53	7.51
7/26/1971	8.13	7.65	8.54	7.52
7/27/1971	8.17	7.65	8.55	7.52
7/28/1971	8.18	7.66	8.56	7.52
7/29/1971	8.23	7.68	8.56	7.52
7/30/1971	8.25	7.67	8.57	7.52
7/31/1971	8.3	7.69	8.58	7.53
8/1/1971	8.41	7.71	8.59	7.53
8/2/1971	8.59	7.74	8.6	7.53
8/3/1971	8.69	7.76	8.61	7.54
8/4/1971	8.73	7.78	8.62	7.54
8/5/1971	8.76	7.79	8.63	7.54
8/6/1971	8.77	7.78	8.65	7.55
8/7/1971	8.8	7.79	8.66	7.55
8/8/1971	8.85	7.8	8.67	7.55
8/9/1971	8.91	7.81	8.69	7.55
8/10/1971	9.01	7.82	8.7	7.56
8/11/1971	9.04	7.83	8.71	7.56
8/12/1971	9.1	7.84	8.73	7.56
8/13/1971	9.15	7.85	8.74	7.57
8/14/1971	9.21	7.86	8.76	7.57
8/15/1971	9.26	7.87	8.78	7.57
8/16/1971	9.35	7.89	8.79	7.57
8/17/1971	9.39	7.9	8.82	7.58
8/18/1971	9.43	7.9	8.84	7.58
8/19/1971	9.5	7.91	8.87	7.58
8/20/1971	9.64	7.93	8.92	7.58
8/21/1971	9.69	7.94	8.95	7.59
8/22/1971	9.75	7.94	9.01	7.59
8/23/1971	9.83	7.95	9.06	7.59
8/24/1971	9.91	7.96	9.12	7.59
8/25/1971	9.96	7.97	9.22	7.6
8/26/1971	10.05	7.97	9.27	7.6
8/27/1971	10.12	7.98	9.38	7.6
8/28/1971	10.2	7.99	9.45	7.6
8/29/1971	10.26	8	9.55	7.61
8/30/1971	10.32	8	9.63	7.61
8/31/1971	10.35	8.01	9.7	7.61
9/1/1971	10.46	8.02	9.8	7.61
9/2/1971	10.5	8.03	9.9	7.61
9/3/1971	10.54	8.03	9.97	7.62
9/4/1971	10.57	8.04	10.06	7.62
9/5/1971	10.6	8.05	10.13	7.62

all ˚C	2009 Meteorology		2012 Meteorology	
Date	**Base285**	**Alt1a**	**Base285**	**Alt1a**
9/6/1971	10.63	8.05	10.21	7.62
9/7/1971	10.66	8.06	10.3	7.62
9/8/1971	10.69	8.06	10.38	7.63
9/9/1971	10.72	8.07	10.45	7.63
9/10/1971	10.78	8.08	10.51	7.63
9/11/1971	10.83	8.08	10.58	7.63
9/12/1971	10.89	8.09	10.66	7.63
9/13/1971	10.95	8.1	10.74	7.64
9/14/1971	11.01	8.1	10.79	7.64
9/15/1971	11.09	8.11	10.85	7.64
9/16/1971	11.17	8.11	10.94	7.64
9/17/1971	11.23	8.12	11	7.64
9/18/1971	11.3	8.12	11.06	7.64
9/19/1971	11.36	8.13	11.1	7.64
9/20/1971	11.41	8.13	11.15	7.65
9/21/1971	11.6	8.15	11.2	7.65
9/22/1971	11.59	8.15	11.24	7.65
9/23/1971	11.63	8.16	11.29	7.65
9/24/1971	11.67	8.16	11.33	7.65
9/25/1971	11.71	8.17	11.37	7.66
9/26/1971	11.75	8.17	11.39	7.66
9/27/1971	11.85	8.18	11.43	7.66
9/28/1971	12.13	8.19	11.49	7.66
9/29/1971	12	8.2	11.53	7.66
9/30/1971	12	8.21	11.59	7.66
10/1/1971	11.98	8.22	11.66	7.66
10/2/1971	11.49	8.24	11.74	7.66
10/3/1971	10.93	8.29	11.82	7.67
10/4/1971	10.84	8.29	11.93	7.67
10/5/1971	10.8	8.3	12.06	7.67
10/6/1971	10.79	8.31	12.22	7.67
10/7/1971	10.32	8.33	12.23	7.67
10/8/1971	10.11	8.35	11.99	7.67
10/9/1971	10.05	8.36	11.75	7.68
10/10/1971	10.05	8.37	11.73	7.68
10/11/1971	9.87	8.39	11.68	7.68
10/12/1971	9.6	8.41	11.37	7.68
10/13/1971	9.4	8.43	11.31	7.68
10/14/1971	9.38	8.47	11.29	7.69
10/15/1971	9.32	8.49	11.23	7.69
10/16/1971	9.16	8.53	10.92	7.69
10/17/1971	9.06	8.58	10.91	7.69
10/18/1971	8.99	8.64	10.91	7.7
10/19/1971	9.02	8.7	10.62	7.71
10/20/1971	9.02	8.75	10.17	7.72
10/21/1971	8.97	8.8	10.09	7.74
10/22/1971	8.87	8.84	9.87	7.78
10/23/1971	8.64	8.86	9.81	7.79
10/24/1971	8.49	8.77	9.8	7.8
10/25/1971	8.32	8.64	9.79	7.82
10/26/1971	8.14	8.4	9.78	7.83
10/27/1971	7.89	8.29	9.67	7.85
10/28/1971	7.6	8.08	9.43	7.87
10/29/1971	7.47	7.93	9.21	7.9
10/30/1971	7.34	7.9	9.05	7.93
10/31/1971	6.77	7.57	8.85	7.97
11/1/1971	6.32	7.17	8.71	8.01
11/2/1971	6.09	6.94	8.66	8.06
11/3/1971	6.06	6.91	8.64	8.11
11/4/1971	6.07	6.91	8.59	8.16
11/5/1971	6.07	6.93	8.54	8.2
11/6/1971	6.08	6.94	8.35	8.24

all ˚C	2009 Meteorology		2012 Meteorology	
Date	**Base285**	**Alt1a**	**Base285**	**Alt1a**
11/7/1971	6.06	6.96	8.22	8.25
11/8/1971	6.05	6.97	8.09	8.16
11/9/1971	6.05	6.98	8.01	8.1
11/10/1971	6.05	6.99	7.95	8.07
11/11/1971	6.05	6.99	7.94	8.07
11/12/1971	6.02	6.97	7.89	8.06
11/13/1971	5.96	6.92	7.66	7.92
11/14/1971	5.91	6.89	7.42	7.7
11/15/1971	5.84	6.83	7.09	7.5
11/16/1971	5.74	6.75	6.93	7.38
11/17/1971	5.66	6.63	6.86	7.3
11/18/1971	5.56	6.47	6.83	7.28
11/19/1971	5.43	6.43	6.68	7.19
11/20/1971	5.38	6.42	6.62	7.18
11/21/1971	5.34	6.4	6.57	7.16
11/22/1971	5.31	6.36	6.53	7.12
11/23/1971	5.23	6.32	6.38	7.01
11/24/1971	4.91	6.11	6.33	6.99
11/25/1971	4.73	5.86	6.3	6.97
11/26/1971	4.58	5.64	6.16	6.86
11/27/1971	4.49	5.54	6.07	6.74
11/28/1971	4.42	5.42	5.93	6.61
11/29/1971	4.36	5.35	5.81	6.52
11/30/1971	4.32	5.3	5.57	6.37
12/1/1971	4.24	5.29	5.44	6.27
12/2/1971	4.12	5.3	5.36	6.2
12/3/1971	4	5.23	5.3	6.19
12/4/1971	3.98	5.14	5.25	6.17
12/5/1971	3.97	4.77	5.24	6.21
12/6/1971	3.94	4.61	5.19	6.14
12/7/1971	3.96	4.54	5.17	6.12
12/8/1971	3.96	4.37	5.12	6
12/9/1971	3.97	4.32	5.01	5.98
12/10/1971	3.97	3.98	4.89	5.9
12/11/1971	3.94	3.96	4.73	5.8
12/12/1971	3.89	3.92	4.49	5.64
12/13/1971	3.91	3.91	4.3	5.38
12/14/1971	3.86	3.88	4.21	5.17
12/15/1971	3.9	3.85	4.16	5.01
12/16/1971	3.91	3.83	4.06	4.97
12/17/1971	3.92	3.81	3.98	4.97
12/18/1971	3.94	3.8	3.98	4.97
12/19/1971	3.92	3.77	3.98	4.86
12/20/1971	3.92	3.73	3.98	4.73
12/21/1971	3.9	3.72	3.98	4.66
12/22/1971	3.91	3.68	3.98	4.51
12/23/1971	3.91	3.66	3.98	4.4
12/24/1971	3.91	3.63	3.98	4.28
12/25/1971	3.94	3.59	3.98	4.23
12/26/1971	3.89	3.52	3.98	4.2
12/27/1971	3.93	3.51	3.98	4.13
12/28/1971	3.93	3.48	3.99	4.07
12/29/1971	3.94	3.46	3.99	3.99
12/30/1971	3.95	3.42	3.99	3.98
12/31/1971	3.98	3.39	3.99	3.96
1/1/1972	3.93	3.32	3.98	3.94
1/2/1972	3.85	3.32	3.99	3.91
1/3/1972	3.8	3.29	3.99	3.87
1/4/1972	3.79	3.24	3.99	3.83
1/5/1972	3.8	3.17	3.99	3.82
1/6/1972	3.81	3.14	3.99	3.8
1/7/1972	3.8	3.09	3.99	3.74

all ˚C	2009 Meteorology		2012 Meteorology	
Date	Base285	Alt1a	Base285	Alt1a
1/8/1972	3.81	3.05	3.99	3.71
1/9/1972	3.82	3.02	3.99	3.68
1/10/1972	3.81	2.98	3.99	3.66
1/11/1972	3.82	2.93	3.99	3.64
1/12/1972	3.78	2.88	3.99	3.62
1/13/1972	3.82	2.84	3.99	3.59
1/14/1972	3.82	2.78	3.99	3.56
1/15/1972	3.82	2.73	3.99	3.55
1/16/1972	3.82	2.67	4	3.52
1/17/1972	3.81	2.63	4	3.52
1/18/1972	3.81	2.57	3.99	3.51
1/19/1972	3.8	2.5	3.99	3.49
1/20/1972	3.81	2.45	3.98	3.46
1/21/1972	3.81	2.39	3.98	3.44
1/22/1972	3.8	2.33	3.98	3.43
1/23/1972	3.79	2.28	3.98	3.41
1/24/1972	3.8	2.22	3.98	3.38
1/25/1972	3.82	2.15	3.98	3.36
1/26/1972	3.82	2.1	3.98	3.34
1/27/1972	3.83	2.03	3.98	3.32
1/28/1972	3.82	1.98	3.98	3.29
1/29/1972	3.82	1.92	3.98	3.27
1/30/1972	3.82	1.85	3.98	3.23
1/31/1972	3.82	1.78	3.98	3.21
2/1/1972	3.82	1.72	3.98	3.2
2/2/1972	3.81	1.67	3.98	3.17
2/3/1972	3.8	1.62	3.98	3.14
2/4/1972	3.78	1.57	3.98	3.11
2/5/1972	3.79	1.53	3.97	3.1
2/6/1972	3.76	1.48	3.97	3.07
2/7/1972	3.78	1.44	3.97	3.05
2/8/1972	3.75	1.4	3.98	3.01
2/9/1972	3.77	1.36	3.98	2.99
2/10/1972	3.76	1.31	3.97	2.97
2/11/1972	3.76	1.27	3.98	2.93
2/12/1972	3.76	1.25	3.97	2.89
2/13/1972	3.77	1.24	3.98	2.85
2/14/1972	3.86	1.24	3.98	2.81
2/15/1972	3.79	1.25	3.97	2.77
2/16/1972	3.78	1.26	3.96	2.72
2/17/1972	3.78	1.27	3.96	2.67
2/18/1972	3.77	1.28	3.96	2.65
2/19/1972	3.75	1.29	3.96	2.61
2/20/1972	3.75	1.31	3.96	2.57
2/21/1972	3.75	1.32	3.95	2.53
2/22/1972	3.76	1.32	3.95	2.5
2/23/1972	3.74	1.33	3.95	2.43
2/24/1972	3.75	1.35	3.97	2.4
2/25/1972	3.74	1.39	3.94	2.37
2/26/1972	3.74	1.41	3.93	2.33
2/27/1972	3.74	1.43	3.94	2.26
2/28/1972	3.7	1.44	3.9	2.24
2/29/1972	3.71	1.48	3.87	2.2
3/1/1972	3.72	1.5	3.91	2.16
3/2/1972	3.71	1.54	3.87	2.12
3/3/1972	3.7	1.59	3.85	2.07
3/4/1972	3.71	1.63	3.86	2.04
3/5/1972	3.7	1.7	3.81	2
3/6/1972	3.69	1.73	3.8	1.96
3/7/1972	3.65	1.75	3.72	1.92
3/8/1972	3.66	1.76	3.73	1.89
3/9/1972	3.62	1.75	3.66	1.83

all ˚C	2009 Meteorology		2012 Meteorology	
Date	**Base285**	**Alt1a**	**Base285**	**Alt1a**
3/10/1972	3.64	1.72	3.66	1.81
3/11/1972	3.62	1.71	3.64	1.77
3/12/1972	3.62	1.71	3.64	1.72
3/13/1972	3.58	1.71	3.63	1.68
3/14/1972	3.58	1.7	3.64	1.65
3/15/1972	3.25	1.69	3.67	1.6
3/16/1972	3.17	1.67	3.7	1.54
3/17/1972	3.17	1.69	3.79	1.5
3/18/1972	3.18	1.73	3.86	1.51
3/19/1972	3.22	1.79	3.89	1.54
3/20/1972	3.22	1.82	3.9	1.55
3/21/1972	3.25	1.88	3.94	1.58
3/22/1972	3.29	1.96	3.98	1.63
3/23/1972	3.3	2.01	3.98	1.68
3/24/1972	3.33	2.02	3.99	1.76
3/25/1972	3.37	2	3.99	1.84
3/26/1972	3.38	1.99	3.99	1.88
3/27/1972	3.42	1.94	3.99	1.95
3/28/1972	3.46	1.94	4	2.03
3/29/1972	3.5	1.89	4	2.11
3/30/1972	3.53	1.83	4	2.2
3/31/1972	3.58	1.82	4.01	2.31
4/1/1972	3.58	1.82	4.02	2.41
4/2/1972	3.62	1.81	4.02	2.54
4/3/1972	3.64	1.78	4.02	2.69
4/4/1972	3.66	1.78	4.03	2.83
4/5/1972	3.69	1.76	4.03	2.85
4/6/1972	3.74	1.7	4.03	2.84
4/7/1972	3.78	1.63	4.04	2.84
4/8/1972	3.83	1.68	4.04	2.87
4/9/1972	3.85	1.69	4.05	2.96
4/10/1972	3.87	1.72	4.05	3.04
4/11/1972	3.89	1.74	4.06	3.14
4/12/1972	3.9	1.74	4.06	3.21
4/13/1972	3.92	1.78	4.07	3.27
4/14/1972	3.94	1.82	4.08	3.33
4/15/1972	3.96	1.87	4.08	3.42
4/16/1972	3.96	1.9	4.08	3.47
4/17/1972	3.96	1.94	4.1	3.5
4/18/1972	3.93	1.93	4.1	3.54
4/19/1972	3.8	1.89	4.11	3.6
4/20/1972	3.91	1.96	4.1	3.66
4/21/1972	3.95	2.01	4.12	3.74
4/22/1972	3.98	2.07	4.13	3.85
4/23/1972	3.99	2.15	4.15	3.95
4/24/1972	3.99	2.22	4.16	3.99
4/25/1972	4	2.28	4.18	4
4/26/1972	4	2.35	4.18	4.04
4/27/1972	4	2.35	4.19	4.06
4/28/1972	4	2.4	4.2	4.09
4/29/1972	4	2.51	4.21	4.1
4/30/1972	4	2.61	4.23	4.11
5/1/1972	4	2.71	4.24	4.15
5/2/1972	4	2.81	4.24	4.19
5/3/1972	4.03	2.79	4.31	4.22
5/4/1972	4.08	2.79	4.34	4.25
5/5/1972	4.26	2.89	4.37	4.3
5/6/1972	4.28	3.04	4.44	4.31
5/7/1972	4.64	3.24	4.46	4.33
5/8/1972	4.88	3.42	4.55	4.36
5/9/1972	4.8	3.5	4.69	4.38
5/10/1972	4.84	3.58	4.73	4.41

all ˚C	2009 Meteorology		2012 Meteorology	
Date	**Base285**	**Alt1a**	**Base285**	**Alt1a**
5/11/1972	4.99	3.67	4.85	4.43
5/12/1972	5.17	3.82	4.98	4.46
5/13/1972	5.66	3.96	5.15	4.48
5/14/1972	5.73	3.99	5.22	4.51
5/15/1972	5.84	4.03	5.4	4.53
5/16/1972	5.84	4.08	5.57	4.56
5/17/1972	5.86	4.14	5.8	4.59
5/18/1972	5.9	4.18	6.01	4.62
5/19/1972	6.16	4.26	6.24	4.66
5/20/1972	6.04	4.29	6.53	4.7
5/21/1972	6.06	4.35	6.68	4.73
5/22/1972	6.08	4.39	6.76	4.77
5/23/1972	6.03	4.45	6.64	4.83
5/24/1972	6	4.66	6.57	4.86
5/25/1972	6	4.78	6.6	4.9
5/26/1972	5.96	4.84	6.55	4.95
5/27/1972	5.88	4.94	6.53	5.01
5/28/1972	5.83	5	6.49	5.05
5/29/1972	5.76	5.06	6.44	5.12
5/30/1972	5.68	5.08	6.34	5.16
5/31/1972	5.68	5.2	6.27	5.22
6/1/1972	5.63	5.2	6.17	5.3
6/2/1972	5.67	5.3	6.31	5.35
6/3/1972	5.79	5.45	6.37	5.45
6/4/1972	5.81	5.49	6.41	5.53
6/5/1972	5.76	5.52	6.37	5.65
6/6/1972	5.56	5.56	6.08	5.72
6/7/1972	5.64	5.58	6.14	5.82
6/8/1972	5.64	5.6	6.18	5.89
6/9/1972	5.55	5.62	6.07	6
6/10/1972	5.56	5.65	5.96	6.06
6/11/1972	5.67	5.67	5.95	6.17
6/12/1972	5.61	5.7	5.88	6.21
6/13/1972	5.63	5.73	5.91	6.29
6/14/1972	5.68	5.75	5.93	6.35
6/15/1972	5.69	5.78	5.96	6.41
6/16/1972	5.73	5.8	5.98	6.45
6/17/1972	5.75	5.83	6.01	6.5
6/18/1972	5.77	5.85	6.02	6.55
6/19/1972	5.8	5.87	6.09	6.6
6/20/1972	5.82	5.9	6.14	6.75
6/21/1972	5.83	5.94	6.16	6.79
6/22/1972	5.86	5.98	6.19	6.76
6/23/1972	5.87	6.01	6.23	6.8
6/24/1972	5.88	6.05	6.26	6.83
6/25/1972	5.89	6.08	6.32	6.88
6/26/1972	5.89	6.12	6.35	6.89
6/27/1972	5.87	6.16	6.36	6.91
6/28/1972	5.89	6.21	6.37	6.93
6/29/1972	5.9	6.25	6.29	6.94
6/30/1972	5.9	6.27	6.29	6.95
7/1/1972	5.93	6.3	6.3	6.97
7/2/1972	5.94	6.33	6.28	6.97
7/3/1972	5.96	6.36	6.29	6.98
7/4/1972	5.96	6.36	6.29	6.98
7/5/1972	5.99	6.4	6.31	6.99
7/6/1972	6	6.42	6.33	6.99
7/7/1972	6.02	6.44	6.33	7
7/8/1972	6.06	6.47	6.34	7
7/9/1972	6.06	6.49	6.35	7
7/10/1972	6.09	6.5	6.35	7
7/11/1972	6.12	6.51	6.36	7.01

all ˚C	2009 Meteorology		2012 Meteorology	
Date	**Base285**	**Alt1a**	**Base285**	**Alt1a**
7/12/1972	6.13	6.53	6.36	7.01
7/13/1972	6.15	6.54	6.37	7.01
7/14/1972	6.18	6.57	6.37	7.02
7/15/1972	6.2	6.59	6.38	7.02
7/16/1972	6.21	6.61	6.39	7.02
7/17/1972	6.23	6.62	6.39	7.03
7/18/1972	6.24	6.63	6.4	7.03
7/19/1972	6.26	6.64	6.4	7.03
7/20/1972	6.28	6.66	6.41	7.04
7/21/1972	6.31	6.67	6.41	7.04
7/22/1972	6.34	6.68	6.42	7.04
7/23/1972	6.35	6.7	6.43	7.05
7/24/1972	6.4	6.72	6.44	7.05
7/25/1972	6.44	6.72	6.46	7.06
7/26/1972	6.49	6.74	6.48	7.06
7/27/1972	6.55	6.75	6.5	7.06
7/28/1972	6.62	6.76	6.53	7.07
7/29/1972	6.69	6.77	6.61	7.07
7/30/1972	6.78	6.79	6.64	7.07
7/31/1972	6.9	6.8	6.73	7.08
8/1/1972	7.04	6.81	6.8	7.08
8/2/1972	7.21	6.81	6.91	7.08
8/3/1972	7.35	6.82	6.99	7.09
8/4/1972	7.49	6.83	7.09	7.09
8/5/1972	7.63	6.84	7.17	7.09
8/6/1972	7.76	6.85	7.25	7.09
8/7/1972	7.93	6.85	7.34	7.1
8/8/1972	8.08	6.86	7.46	7.1
8/9/1972	8.39	6.87	7.55	7.1
8/10/1972	8.61	6.87	7.67	7.11
8/11/1972	8.85	6.88	7.79	7.11
8/12/1972	9.1	6.89	7.94	7.11
8/13/1972	9.32	6.9	8.11	7.11
8/14/1972	9.55	6.9	8.32	7.12
8/15/1972	9.78	6.91	8.59	7.12
8/16/1972	9.99	6.92	8.88	7.12
8/17/1972	10.24	6.92	9.16	7.12
8/18/1972	10.55	6.93	9.46	7.13
8/19/1972	10.79	6.94	9.76	7.13
8/20/1972	10.95	6.95	10.05	7.13
8/21/1972	11.19	6.96	10.31	7.13
8/22/1972	11.4	6.96	10.62	7.14
8/23/1972	11.62	6.97	10.9	7.14
8/24/1972	11.89	6.98	11.11	7.14
8/25/1972	12.05	6.99	11.35	7.14
8/26/1972	12.26	6.99	11.52	7.15
8/27/1972	12.43	7	11.75	7.15
8/28/1972	12.59	7	11.93	7.15
8/29/1972	12.76	7.01	12.12	7.15
8/30/1972	12.92	7.02	12.28	7.16
8/31/1972	13.19	7.03	12.45	7.16
9/1/1972	13.38	7.03	12.65	7.16
9/2/1972	13.46	7.04	12.83	7.16
9/3/1972	13.58	7.04	13	7.17
9/4/1972	13.73	7.05	13.17	7.17
9/5/1972	13.9	7.06	13.33	7.17
9/6/1972	14.07	7.07	13.51	7.18
9/7/1972	14.23	7.07	13.66	7.18
9/8/1972	14.35	7.08	13.81	7.18
9/9/1972	14.44	7.09	13.94	7.18
9/10/1972	14.53	7.1	14.07	7.18
9/11/1972	14.58	7.1	14.21	7.19

all ˚C	2009 Meteorology		2012 Meteorology	
Date	**Base285**	**Alt1a**	**Base285**	**Alt1a**
9/12/1972	14.59	7.11	14.25	7.19
9/13/1972	14.28	7.11	14.35	7.19
9/14/1972	14.25	7.12	14.4	7.19
9/15/1972	14.26	7.13	14.51	7.2
9/16/1972	14.26	7.13	14.54	7.2
9/17/1972	14.26	7.14	14.55	7.2
9/18/1972	14.21	7.14	14.56	7.2
9/19/1972	14.18	7.15	14.31	7.2
9/20/1972	14.15	7.16	14.24	7.21
9/21/1972	13.87	7.17	14.17	7.21
9/22/1972	13.55	7.17	14.11	7.21
9/23/1972	13.4	7.18	14.08	7.21
9/24/1972	13.16	7.18	14.03	7.22
9/25/1972	13.1	7.19	13.97	7.22
9/26/1972	13.03	7.2	13.8	7.22
9/27/1972	12.81	7.22	13.67	7.22
9/28/1972	12.69	7.23	13.54	7.22
9/29/1972	12.67	7.23	13.44	7.23
9/30/1972	12.61	7.24	13.36	7.23
10/1/1972	12.01	7.29	13.32	7.23
10/2/1972	11.34	7.34	13.3	7.23
10/3/1972	11.23	7.35	13.2	7.24
10/4/1972	11.23	7.37	13.15	7.24
10/5/1972	11.2	7.38	13.1	7.24
10/6/1972	10.68	7.39	12.73	7.24
10/7/1972	10.45	7.4	12.49	7.24
10/8/1972	10.4	7.41	12.22	7.25
10/9/1972	10.25	7.42	12.16	7.25
10/10/1972	10.09	7.44	12.01	7.25
10/11/1972	9.76	7.46	11.7	7.26
10/12/1972	9.55	7.48	11.63	7.26
10/13/1972	9.51	7.5	11.63	7.26
10/14/1972	9.51	7.53	11.57	7.26
10/15/1972	9.41	7.56	11.26	7.26
10/16/1972	9.25	7.58	11.2	7.27
10/17/1972	9.13	7.62	11.14	7.27
10/18/1972	9.12	7.69	10.97	7.27
10/19/1972	9.12	7.72	10.41	7.28
10/20/1972	9.08	7.78	10.3	7.28
10/21/1972	9.02	7.83	10.14	7.29
10/22/1972	8.76	7.88	10.05	7.29
10/23/1972	8.67	7.93	10.04	7.3
10/24/1972	8.43	8.02	10.01	7.31
10/25/1972	8.23	7.94	10	7.32
10/26/1972	7.99	7.77	9.91	7.33
10/27/1972	7.77	7.58	9.63	7.35
10/28/1972	7.6	7.41	9.47	7.37
10/29/1972	7.48	7.37	9.22	7.39
10/30/1972	6.81	7.06	9.08	7.42
10/31/1972	6.51	6.66	8.95	7.45
11/1/1972	6.36	6.4	8.9	7.49
11/2/1972	6.35	6.38	8.86	7.52
11/3/1972	6.33	6.39	8.79	7.54
11/4/1972	6.29	6.45	8.69	7.64
11/5/1972	6.2	6.56	8.52	7.71
11/6/1972	6.22	6.54	8.36	7.97
11/7/1972	6.23	6.56	8.27	8.17
11/8/1972	6.23	6.58	8.19	8.17
11/9/1972	6.2	6.56	8.18	8.15
11/10/1972	6.16	6.54	8.12	8.14
11/11/1972	6.07	6.52	7.97	8.1
11/12/1972	6.03	6.48	7.74	7.98

all ˚C	2009 Meteorology		2012 Meteorology	
Date	**Base285**	**Alt1a**	**Base285**	**Alt1a**
11/13/1972	5.97	6.45	7.23	7.77
11/14/1972	5.86	6.39	7.01	7.56
11/15/1972	5.75	6.32	6.91	7.44
11/16/1972	5.61	6.23	6.83	7.39
11/17/1972	5.34	6.11	6.77	7.36
11/18/1972	5.28	6.05	6.54	7.3
11/19/1972	5.26	6.03	6.53	7.28
11/20/1972	5.26	6.03	6.52	7.28
11/21/1972	5.26	6.02	6.47	7.25
11/22/1972	5.13	5.96	6.24	7.12
11/23/1972	4.77	5.76	6.23	7.1
11/24/1972	4.48	5.56	6.18	7.08
11/25/1972	4.33	5.42	6.01	6.97
11/26/1972	4.23	5.28	5.86	6.89
11/27/1972	4.18	5.18	5.72	6.74
11/28/1972	4.14	5.12	5.6	6.66
11/29/1972	4.09	5.07	5.36	6.52
11/30/1972	4	5.05	5.25	6.42
12/1/1972	3.98	5.04	5.16	6.35
12/2/1972	3.97	4.99	5.12	6.33
12/3/1972	3.96	4.9	5.1	6.32
12/4/1972	3.46	4.55	5.08	6.3
12/5/1972	3.28	4.35	4.97	6.27
12/6/1972	3.28	4.24	4.93	6.24
12/7/1972	3.29	4.19	4.77	6.11
12/8/1972	3.29	4.11	4.74	6.09
12/9/1972	2.93	3.95	4.62	6.01
12/10/1972	1.77	3.85	4.43	5.92
12/11/1972	1.68	3.78	4.17	5.75
12/12/1972	1.62	3.73	3.98	5.48
12/13/1972	1.48	3.72	3.98	5.28
12/14/1972	1.44	3.68	3.97	5.14
12/15/1972	1.37	3.67	3.97	5.09
12/16/1972	1.32	3.63	3.98	5.08
12/17/1972	1.25	3.6	3.97	5.07
12/18/1972	1.24	3.58	3.95	4.95
12/19/1972	1.08	3.56	3.95	4.79
12/20/1972	1.05	3.52	3.88	4.72
12/21/1972	0.75	3.49	3.89	4.58
12/22/1972	0.77	3.45	3.87	4.41
12/23/1972	0.79	3.44	3.87	4.29
12/24/1972	0.8	3.41	3.86	4.25
12/25/1972	0.81	3.36	3.83	4.2
12/26/1972	0.82	3.36	3.83	4.15
12/27/1972	0.83	3.35	3.82	4.1
12/28/1972	0.84	3.32	3.84	4.03
12/29/1972	0.83	3.29	3.82	3.98
12/30/1972	0.84	3.26	3.84	3.96
12/31/1972	0.84	3.21	3.83	3.92